

A STANDARD OF CARE FOR LONG-DURATION SPACE MISSIONS: EMERGENCY MEDICINE AS AN INITIAL MODEL

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INTRODUCTION

On December 14, 1972, astronauts Eugene Cernan, Ronald Evans, and Harrison Schmitt departed the lunar surface for the final burn home of the Apollo 17 mission.² Five days later, their crew capsule touched down, marking the last time humanity flew beyond the reach of low-earth orbit.³ After the completion of the Apollo Program, National Aeronautics and Space Administration (“NASA”) reallocated funding to other programs within the agency, proposed and cancelled a myriad of missions,⁴ and contained the Space Shuttle’s flights to low-earth orbit.⁵ The International Space Station (“ISS”) remains the single bastion of humanity in space.⁶ Other than the Apollo missions, the majority of spaceflight has been, and still is, conducted in the low-earth orbit.⁷

Scientist have been conducting medical research on the effects of spaceflight since 1952 when Sputnik 2 launched into space carrying Laika, the first animal to orbit the Earth.⁸ While NASA has gathered decades’ worth of research on the effect of spaceflight on human beings, the research pool has been strikingly, though understandably, narrow. Only 24 astronauts have broken beyond low-earth orbit.⁹

² *Apollo 17: Mission Objective*, NAT'L AERONAUTICS & SPACE ADMIN. (Apr. 7, 2011), https://www.nasa.gov/mission_pages/apollo/missions/apollo17.html.

³ *Id.*; see also Andrew Liptak, *The Real Story of Apollo 17 . . . And Why We Never Went Back To the Moon*, GIZMODO (Dec. 12, 2015, 9:22 PM), <https://io9.gizmodo.com/the-real-story-of-apollo-17-and-why-we-never-went-back-to-the-moon-1670503448>.

⁴ See Liptak, *supra* note 3.

⁵ Low-earth orbit, defined as orbit at an altitude between 160 and 1,000 kilometers, is where all modern manned spaceflight occurs. *Types of Orbits*, EUROPEAN SPACE AGENCY (Apr. 17, 2017), http://www.esa.int/Our_Activities/Space_Transportation/Types_of_orbits.

⁶ See generally Liptak, *supra* note 3 (discussing in part NASA’s changing focus after the end of the Apollo missions).

⁷ *Id.*

⁸ *NASA Space Science Data Coordinated Archive: Sputnik 2*, NAT'L AERONAUTICS & SPACE ADMIN., <https://nssdc.gsfc.nasa.gov/nmc/spacecraft/display.action?id=1957-002A> (last visited Aug. 24, 2019).

⁹ See generally *Apollo Missions*, NAT'L AERONAUTICS & SPACE ADMIN., <https://www.nasa.gov/specials/apollo50th/missions.html> (last visited Oct. 6, 2019) (indicating that all Apollo missions, except Apollo 1, 7, and 9, traveled beyond low-earth orbit).

These astronauts were all uniformly white, male, and between 36 and 47 years old at the time of their missions,¹⁰ and a majority of them have a military background.¹¹ The maximum mission length was twelve and a half days.¹² Despite the relatively short length of the missions, several medical issues occurred during the Apollo missions: Apollo 7 “became known as the ‘ten-day cold capsule’ after the entire crew developed viral upper respiratory infections”;¹³ one Apollo 13 astronaut acquired a urinary tract infection;¹⁴ every Apollo 10 astronaut suffered ocular fiberglass irritation for two days;¹⁵ and all 24 astronauts were exposed to doses of high-energy radiation.¹⁶ Still, because of the small number of astronauts compared to the general population and the short duration of the missions, the scope of medical research acquired from astronauts who have gone beyond low-earth orbit has been extremely limited.¹⁷

While astronauts have suffered a number of illnesses and health effects during missions, no in-flight medical emergencies have occurred in the history of human spaceflight.¹⁸ Spaceflight deaths have occurred, but they were the result of sudden engineering or mechanical issues—not situations where emergency treatment could

¹⁰ See *Biographies of Apollo 11 Astronauts*, NAT'L AERONAUTICS & SPACE ADMIN., <https://history.nasa.gov/ap11ann/astrobios.htm> (last visited Oct. 18, 2019). See also NASA *Former Astronauts*, NAT'L AERONAUTICS & SPACE ADMIN., <https://www.nasa.gov/astronauts/biographies/former> (last visited Oct. 18, 2019).

¹¹ See *id.*

¹² See *The Apollo Program (1963-1972)*, NAT'L AERONAUTICS & SPACE ADMIN., (Sep. 16, 2013), <https://nssdc.gsfc.nasa.gov/planetary/lunar/apollo.html>.

¹³ Lowan H. Stewart et al., *Emergency Medicine in Space*, 32 J. EMERGENCY MED. 45, 45 (2007).

¹⁴ *Inflight Problems in Apollo Medical Crews*, NAT'L AERONAUTICS & SPACE ADMIN., (Apr. 10, 2018), https://history.nasa.gov/SP-4029/Apollo_18-45_Inflight_Medical_Problems.htm.

¹⁵ Richard A. Scheuring et al., *The Apollo Medical Operations Project: Recommendations to Improve Crew Health and Performance for Future Exploration Missions and Lunar Surface Operations*, NAT'L AERONAUTICS & SPACE ADMIN. 88, 350 (Aug. 2007).

¹⁶ Stewart et al., *supra* note 13, at 49.

¹⁷ See *FUNDAMENTALS OF AEROSPACE MEDICINE* 708-709 (Jeffrey R. Davis et al. eds., 4th ed. 2008).

¹⁸ Richard L. Summers et al., *Emergencies in Space*, 46 ANNALS EMERGENCY MED. 177, 177 (Aug. 2005).

be timely administered.¹⁹ For example, three cosmonauts died in 1971 when the Russian Soyuz 11 capsule suffered rapid decompression during entry.²⁰ Also, three Apollo 1 astronauts perished in a fire resulting from their pure oxygen environment and a complicated means of egress.²¹ In total, there have been 18 fatalities during spaceflight,²² but none of the in-flight fatalities were ones in which medical intervention would have saved the life of an astronaut.²³ As many modern space programs, particularly NASA, intend to soon begin sending astronauts on long-duration flights beyond low-earth orbit, the fact no in-flight fatalities were ones where medical intervention could have been beneficial is not likely to remain the case for long.²⁴ As of this writing, one of NASA's stated goals is to "send humans to Mars by the early 2030s."²⁵ The early 2030s is an aggressive deadline by which NASA needs to conduct an enormous amount of research. In particular, NASA will need to discern how medical care can be conducted safely and effectively during deep space travel.

The first of these planned manned missions involves sending astronauts to simply orbit Mars, which has a mission duration of approximately 21 months.²⁶ Few NASA astronauts have conducted missions close to that length—the longest has been Scott Kelly's 340-day mission.²⁷ However, each long-duration mission to-date has been conducted in low-earth orbit.²⁸ Concedingly, medical research is

¹⁹ See William Harwood, *Astronaut Fatalities*, SPACEFLIGHT NOW, <https://spaceflightnow.com/shuttle/sts114/fdf/fatalities.html> (last visited Aug. 24, 2019).

²⁰ Stewart et. al, *supra* note 13, at 45; see also Harwood, *supra* note 19.

²¹ Nat'l Aeronautics & Space Admin., Report of Apollo 204 Board to Adm'r, Nat'l Aeronautics & Space Admin., Appx. D, D-13-11-D-13-13 (last visited Sept. 29, 2019).

²² Harwood, *supra* note 19.

²³ *See id.*

²⁴ Summers et al., *supra* note 18, at 177-78.

²⁵ *Journey to Mars Overview*, NAT'L AERONAUTICS & SPACE ADMIN., <https://www.nasa.gov/content/journey-to-mars-overview> (last visited Apr. 5, 2019).

²⁶ *How Long Would a Trip to Mars Take?*, NAT'L AERONAUTICS & SPACE ADMIN., <https://image.gsfc.nasa.gov/poetry/venus/q2811.html> (last visited Oct. 18, 2019).

²⁷ *NASA Astronaut Scott Kelly Returns Safely to Earth after One-Year Mission*, NAT'L AERONAUTICS & SPACE ADMIN. (Mar. 1, 2016), <https://www.nasa.gov/press-release/nasa-astronaut-scott-kelly-returns-safely-to-earth-after-one-year-mission/>.

²⁸ *See generally Apollo Missions*, *supra* note 9.

constantly conducted on the ISS;²⁹ however, several conditions of an exploration-class mission are not reproducible, such as radiation exposure, lack of resupply (with the attendant requirement of total self-reliance), communication delay, and inability to return home or evacuate in the event of an emergency.³⁰ Earth-based analogues continue to study some of these problems,³¹ but they are limited and will never fully reproduce an actual deep space environment.

Therefore, NASA must further its research developing countermeasures to the hazards of long-duration space flight on human health. This article aims to expand the existing body of knowledge by analyzing the current standard of care for spaceflight and identifying elements of the standard of care that will need to change in order to respond to medical challenges on an exploration-class mission, particularly in regard to medical emergencies. Medical emergencies are salient because they involve a significant human factor that can determine the outcome of the emergency, which is a large “make or break” for continued mission success. Specifically, this article aims to highlight what changes will be necessary to the existing trauma standard of care and medical framework that NASA currently uses for spaceflight missions. First, this article begins by describing why space medicine is an important factor when considering what changes are needed to the current spaceflight medical standard of care, with a discussion on risks related to medical emergencies in long-duration spaceflight. Next, this article presents an overview of the current state of the spaceflight medical research, astronaut health standards, space medical standards of care, and ethical standards, and it describes a potential emergency medical scenario that illustrates the need to change the current standard of care. Finally, this article argues that it is imperative a physician-astronaut be attached to each exploration-class mission.

²⁹ NAT'L AERONAUTICS & SPACE ADMIN., HRP-48006, Human Research Program Utilization Plan for the Int'l Space Station, 2014 Update (Apr. 2015).

³⁰ See generally *How Long Would a Trip to Mars Take?*, *supra* note 26 (discussing in part special logistical and medical considerations for long-duration missions).

³¹ See generally *Human Research Program Evidence*, NAT'L AERONAUTICS & SPACE ADMIN., <https://humanresearchroadmap.nasa.gov/Evidence/> (last visited Oct. 18, 2019) (listing NASA Human Research Program Evidence Reports for various human health and performance risks studies).

I. BACKGROUND AND RISK

A. Background on Challenges for Long-Duration Spaceflight

Space is the most hostile environment known to life. Life was eventually able to develop on Earth due to its location within a “habitable zone.”³² The human species is well-adapted to life on Earth because humankind has never been exposed to conditions outside of a small range. However, space is almost the exact opposite of these conditions on Earth, and the space environment has bedeviled spacecraft engineers and astronauts since Sputnik. Although it is relatively easy to send an unmanned spacecraft into orbit, the addition of astronauts complicates spacecraft design. Life support systems must be added to take into account the mass of the crew members and their consumables. As allowances for equipment storage become tighter, the need for medical equipment must be balanced with every other requirement necessary for human survival in space. With these conditions in mind, it is easy to see why keeping astronauts alive has been a daunting task from the beginning of the spacecraft design process.

Space medicine is a key component of the spacecraft design process that extends throughout the entirety of the spacecraft’s functional life. Proper consideration of space medicine is integral to the success of an exploration-class mission because space medicine has the potential to largely reduce the risk of death or debilitation from an otherwise preventable onboard medical event. Proper consideration of space medicine requirements for spaceflight will also benefit medical research because it will provide an opportunity for more data to be recorded, which will allow subsequent missions to better implement countermeasures in light of the research gained.

Spacecrafts are at the mercy of physics and orbital mechanics. Evacuation from the ISS is already difficult enough. From the decision to evacuate to landing, the evacuation process is a minimum of three

³² A “habitable zone” is one where the temperature and distance from the sun makes a planetary surface compatible for the existence of water. *Warm Welcome: Finding Habitable Planets*, NAT'L AERONAUTICS & SPACE ADMIN., <https://exoplanets.nasa.gov/what-is-an-exoplanet/how-do-we-find-habitable-planets/> (last visited Oct. 18, 2019).

and a half hours.³³ An additional complication to the evacuation design is the mechanics of evacuating. The current evacuation craft, a Soyuz capsule, is designed for three astronauts in spacesuits to sit upright in an extremely confined space.³⁴ The emergency evacuation orbit is steeper than the normal descent, and the g-forces (i.e., the physical force that occurs during acceleration) are subsequently higher, which would likely impact whatever medical event initiated the evacuation (e.g., a broken bone would receive further stress under g-force loads of evacuation).

The hypothesized evacuation of the ISS is still a lower risk posture than that of a long-duration mission because evacuation is possible. Long-duration deep space missions further complicate the already difficult task of microgravity medical intervention. Once a spacecraft leaves low-earth orbit for a lunar or Mars mission, the astronauts are committed to a trajectory. The spacecraft's trajectory can later be altered within fuel limits. For example, the Apollo 13 astronauts altered their orbit to "slingshot" themselves around the Moon for a faster return to Earth.³⁵ However, once committed to an orbit, it is impossible for modern spacecraft to "turn around" because of the constraints on mass and the amount of force an engine can generate. Traveling to Mars presents even more problems than a lunar mission:

Assuming there are no developments in propulsion technology, even a Mars "fly-by" with direct return to Earth may represent a 9-month round trip. The entire trip may last as long as 1000 days. Radio communication will require up to 20 minutes to reach Mars from Earth . . . extended periods of communication blackout may even leave the Mars explorers without Earth contact for weeks.³⁶

Even though it is considered a long-duration space mission, a lunar crew is not required to be entirely medically self-sufficient; rather, it is only required to ensure enough resources are available to keep a

³³ *Soyuz Landing*, Nat'l AERONAUTICS & SPACE ADMIN., (Sep. 15, 2011) https://www.nasa.gov/mission_pages/station/structure/elements/soyuz/landing.html.

³⁴ See *id.*

³⁵ *Apollo 13*, NAT'L AERONAUTICS & SPACE ADMIN., (July 8, 2009) https://www.nasa.gov/mission_pages/apollo/missions/apollo13.html.

³⁶ Maybritt I. Kuypers, *Emergency and Wilderness Medicine Training for Physician Astronauts on Exploration Class Missions*, 24 WILDERNESS & ENVTL. MED. 445, 445 (Dec. 2013).

medical emergency stabilized until a return to Earth becomes possible. In contrast, a Mars mission is the longest duration planned space mission, which necessitates self-sufficiency for the mission. For the astronauts on Mars missions, those chosen will be required to assume a higher degree of risk than any previous astronauts.

In 2015, the NASA Office of Inspector General ("OIG") identified 30 main issues the agency views as the preeminent risks to manned deep space missions.³⁷ In a 2015 report, the OIG defined the categories as "[l]imited resources[,] . . . [i]solation[,] . . . [h]ostile/closed environment spacecraft design[,] . . . [a]ltered gravity[, and] . . . [s]pace radiation."³⁸ The 30 human health and performance risks are all categorized under these 5 space environment hazard labels (although 2 of the 30 are not yet formally defined as risks):



Source: Human Research Program, 2015.

^a Concern.

^b Pharmacokinetics is the study of the movement of drugs in the body.

^c Risk has been retired.

Figure 1³⁹

Excepting space radiation exposure, these identified risks could cause or lead to various types of in-flight medical emergencies. While

³⁷ See OFFICE OF INSPECTOR GEN., NAT'L AERONAUTICS & SPACE ADMIN., REPORT NO. IG-16-003, NASA'S EFFORTS TO MANAGE HEALTH AND HUMAN PERFORMANCE RISKS FOR SPACE EXPLORATION 2-4 (2015), <https://oig.nasa.gov/audits/reports/FY16/IG-16-003.pdf>.

³⁸ *Id.* at 2-3.

³⁹ *Id.* at 4.

comprehensive with respect to risks, the OIG's list does not describe specifically which emergencies may happen or identify the likely risk levels of potential emergencies.

B. Risk Analysis for Medical Emergencies in Long-Duration Spaceflight

NASA is a research agency working in some of the most high-risk activities possible. While spaceflight is inherently difficult, adding a human crew into the equation complicates it further. NASA's risk management "comprises two integrated efforts: risk-informed decision making and continuous risk management processes."⁴⁰ Through these efforts, NASA identifies risks "based on historical precedence (lessons learned and empirical data), on possible failures in laboratory tests, and in discussions with subject matter experts."⁴¹ When NASA determines that a risk is beyond an acceptable range, "alternative designs and mission scenarios are considered, and the risk assessment continues iteratively."⁴² NASA has flown astronauts since Project Mercury began in 1958,⁴³ and it has developed an understanding of the human health risks associated with spaceflight. While long-duration missions still have many unknown risks, NASA has developed strategies to mitigate known and possible risks. Radiation, for example, is a known risk that does not yet have an engineering-based solution. If NASA considers the "radiation exposure in a particular mission . . . too high," then NASA designs the mission and mission vehicle with in light of these considerations.⁴⁴ Without an "engineering or mission design solution to mitigate the risk," then NASA will consider "other alternatives . . . such as redesign

⁴⁰ COMM. ON ETHICS PRINCIPLES & GUIDELINES FOR HEALTH STANDARDS FOR LONG DURATION & EXPLORATION SPACEFLIGHTS, HEALTH STANDARDS FOR LONG DURATION & EXPLORATION SPACEFLIGHT: ETHICS, PRINCIPLES, RESPONSIBILITIES, A DECISION FRAMEWORK 26 (Jeffrey Kahn et al. eds., 2014) [hereinafter HEALTH STANDARDS].

⁴¹ *Id.* at 26.

⁴² *Id.*

⁴³ About Project Mercury, NAT'L AERONAUTICS & SPACE ADMIN., https://www.nasa.gov/mission_pages/mercury/missions/program-toc.html (last visited Oct. 18, 2019).

⁴⁴ HEALTH STANDARDS, *supra* note 40, at 27.

of the mission, delays in the mission until technology is available, or making exceptions to the standards.”⁴⁵ With these points in mind, how should NASA then think about risk for a medical emergency on a long-duration mission?

A study by led Dr. Richard L. Summers offers one risk analysis for the potential of a Mars mission medical emergency.⁴⁶ As a first step:

[U]sing actuarial data, it is possible to estimate the risk of an emergency medical event during space flight. In the general population, the emergency incidence rate is usually considered to be about .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 .06 events per person year x 7 persons x 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.⁴⁷

The authors note that this data is for the general population; however, astronaut candidates receive a thorough health screening process.⁴⁸ Otherwise qualified candidates have been, and will continue to be, disqualified for health issues that carry a slight risk of becoming problematic during spaceflight. For example, chronic conditions like asthma require medication for continual maintenance.⁴⁹ Storing these medications for a mission to Mars would require a significant allocation of the space craft’s volume and mass. Future long-distance space missions must make difficult decisions when planning the crew and trajectory of the mission, including considerations such as “how to optimize the integration of family history, physical and laboratory findings, and current genetic data to help predict future disease or disability in astronauts being considered for initial selection or assignment on long-duration space missions.”⁵⁰ Given the rigorous selection process already that already exists for NASA astronauts,

⁴⁵ *Id.*

⁴⁶ See generally Summers et al., *supra* note 18.

⁴⁷ *Id.* at 177.

⁴⁸ *Id.*

⁴⁹ See generally U.S. DEP’T OF HEALTH & HUMAN SERVS., NAT’L INST. OF HEALTH, EXPERT PANEL REPORT 3: GUIDELINES FOR THE DIAGNOSIS AND MANAGEMENT OF ASTHMA (Aug. 28, 2007), https://www.nhlbi.nih.gov/sites/default/files/media/docs/asthgdln_1.pdf.

⁵⁰ FUNDAMENTALS OF AEROSPACE MEDICINE, *supra* note 17, at 530.

NASA-manned Mars mission will have crew who are exceptionally fit and healthy.

While the best research cannot be done until after researchers have gathered statistically significant information on the number of emergencies encountered during these long-distance spaceflight missions, it is still possible to use a current terrestrial analogue: the McMurdo research station in Antarctica.⁵¹ Dr. Summers and his team state that based on their evaluation of the "evacuation rates for medical emergencies from the Antarctic McMurdo Station," their study was able to "calculate an incidence of 0.036 events per person-year."⁵² The Summers study postulates that the medical and environmental circumstances of the Antarctic McMurdo Station "may reflect the conditions faced by astronauts, although the potential for an emergency medical event may be somewhat different."⁵³ The main difference is that 48% of the McMurdo evacuations were caused by traumatic injuries, while there have been only 17 severe medical events (such as burns, cellulitis, renal stones, and heart arrhythmia) in the history of spaceflight from inception until 1999.⁵⁴ As of this writing, there have still been no traumatic events, though the number of severe events has increased.⁵⁵

⁵¹ Summers et al., *supra* note 18, at 178.

⁵² *Id.*

⁵³ *Id.*

⁵⁴ *Id.* at 178.

⁵⁵ See Crucian et al., *Incidence of Clinical Symptoms During Long-Duration Spaceflight*, 3 INT'L J. GENERAL MED. 383, 388-89 (Nov. 3, 2016).

II. RESEARCH PROGRESS, CURRENT STANDARDS, AND EMERGENCY MEDICINE AS A BASELINE



Figure 2⁵⁶

Research in space medicine is ongoing, but it is hindered in part by environment and in part by a lack of available research. Much of the needed research is, in turn, limited by current capabilities and risk assessments towards human health.⁵⁷ Eventually, risk standards will need to be less strict if astronauts are to undertake long-duration missions. Emergency medicine may offer a model as to how risk can be managed during a long-duration flight.

A. Gaps Identified in Exploration Medical Capability (“ExMC”) Research

As part of its ongoing research, NASA directs ExMC to assess certain issues—identifying the current evidence, risks, and gaps in its

⁵⁶ Paolo Nespoli (@astro_paolo), TWITTER (Aug. 30, 2017, 12:50 PM), https://twitter.com/astro_paolo/status/902981995021651969.

⁵⁷ See NAT'L ACADEMIES OF SCIENCES, ENGINEERING & MEDICINE, REVIEW OF NASA'S EVIDENCE REPORTS ON HUMAN HEALTH RISKS: RISK OF ADVERSE HEALTH OUTCOMES AND DECREMENTS IN PERFORMANCE DUE TO IN-FLIGHT MEDICAL CONDITIONS 26-30 (2017), <http://www.doi.org/10.17226/24953> [hereinafter NAT'L ACADEMIES REVIEW OF EVIDENCE REPORT ON HUMAN HEALTH RISKS].

protocols, so that the agency can better prepare for the medical aspects of a long-duration mission.⁵⁸ ExMC is one of the elements of NASA's Human Research Program outlined in its Integrated Research Plan.⁵⁹ The Integrated Research Plan is NASA's targeted risk identification and mitigation strategy, which delivers "human health and performance countermeasures, knowledge, technologies, and tools to enable safe, reliable, and productive human space exploration."⁶⁰

Ensuring that these tasks are met is one of the foremost problems NASA must solve before long-duration missions can occur. In their efforts to solve these problems for long-duration space missions, NASA will need to shift its focus from the current model of ground-based and ISS-centric research to focus on the unknown medical aspects of current human spaceflight. ExMC is one method through which NASA has attempted to further this goal. The group's research focuses on "establishing evidenced-based methods of monitoring and maintaining astronaut health."⁶¹ To do this, ExMCs advance "techniques that identify, prevent, and treat any health threats that may occur during space missions."⁶² Monitoring and maintaining astronaut health is a broad prerogative, and as such NASA focuses on systems engineering methodologies to "[address] clinical, behavioral health, human factors, physiological performance, and task performance needs."⁶³ Many of the issues brought up in this paper are current ExMC research targets.⁶⁴

⁵⁸ See generally Nat'l Aeronautics & Space Admin., Human Research Program, HRP 47065, Rev. K, Human Research Program Integrated Research Plan 16-17 (July 2019), https://humanresearchroadmap.nasa.gov/Documents/IRP_Rev-Current.pdf (describing ExMC as an element of NASA's current Human Research Program) [hereinafter HRP 47065, Rev. K].

⁵⁹ *Id.* at 11, 16-17.

⁶⁰ *Id.* at 7.

⁶¹ *Id.* at 18.

⁶² *Id.*

⁶³ *Id.*

⁶⁴ See generally *Human Research Program: Risks*, NAT'L AERONAUTICS & SPACE ADMIN., <https://humanresearchroadmap.nasa.gov/Risks/> (last visited Oct. 18, 2019) (enumerating risk-related areas of study under NASA's Human Research Program).

ExMC research organizes medical capability gaps into different areas, such as surgical or cardiovascular.⁶⁵ The most important gap is Med01, which encompasses “medical care during exploration missions,” because NASA “[does] not have a concept of operations” for this category.⁶⁶ That is not to say NASA has no ideas on what a standard of care may look like for long-duration missions; rather, there are currently too many other gaps in the research for NASA to positively identify what the medical capabilities of a long-distance spacecraft and its crew should be. Specifically, Med01 “identifies the need to adapt the current low-earth orbit perspective of practicing medicine to the exploration context.”⁶⁷ A fundamental component of Med01 is the need to define “what capabilities are needed so that the medical resources (e.g., equipment, databases, and the like) are integrated into the overall research system.”⁶⁸ Assessing the medical capability requirements for the spacecraft is integral to the development of the formalized standard of care for a long-duration mission. The standard of care must move away from the low-earth orbit model. However, researchers are still unsettled as to an understanding of the extent to which the standard of care must change to account for a long-duration spaceflight.

B. The Standard of Care in Space Missions

Broadly defined, the framework through which medical professionals practice medicine functions as a quasi-legal framework because the profession has created guidelines for what treatments should be administered or protocols should be followed for a patient presenting with certain complaints and symptoms. The U.S. National Library of Medicine defines the nature of these guidelines:

Institutions, associations, and government agencies issue health related standards and guidelines which are widely used and recognized in the [United States]. Standards are authoritative statements that articulate

⁶⁵ See *id.*

⁶⁶ *Med01: We do not have a concept of operations for medical care during exploration missions*, NAT'L AERONAUTICS & SPACE ADMIN., (July 31, 2018, 10:05 AM), <https://humanresearchroadmap.nasa.gov/Gaps/gap.aspx?i=633>.

⁶⁷ *Id.*

⁶⁸ *Id.*

minimal, acceptable or excellent levels of performance or that describe expected outcomes in health care delivery, biomedical research and development, health care technology, or professional health care. Guidelines are statements of principles or procedures that assist professionals in ensuring quality in such areas as clinical practice, biomedical research, and health services. Practice guidelines assist the health care practitioner with patient care decisions about appropriate diagnostic, therapeutic, or other clinical procedures for specific clinical circumstances.⁶⁹

These guidelines provide medical providers with the information necessary to conduct their treatments. These treatment guidelines can also be used in legal cases when they are taken as "learned medical treatises."⁷⁰ Despite their treatment as authoritative treatises, there is "no set standard for how these documents are used in court cases."⁷¹ When discussing standards of care, the discussion revolves around the definition of "minimal"—this is the standard a provider must prove she achieved when she is defending herself from a malpractice claim.⁷²

While a risk-averse agency like NASA may disagree that the standard of care in space should be "minimal" because the agency strives to provide quality healthcare for astronauts both terrestrially and in space, the agency agrees that the current health standards must change for long-duration spaceflights, as evidenced by the creation of ExMC. A long-duration space mission comes with both known and unknown health risks. As of now, NASA considers even known risks, such as the amount radiation exposure during a long duration mission, unacceptable.⁷³ Indeed, there is currently no standard of care

⁶⁹ *Standards and Guidelines*, COLLECTION DEV. GUIDELINES OF NAT'L LIBR. MED., <https://www.nlm.nih.gov/tsd/acquisitions/cdm/formats46.html> (last visited Oct. 18, 2019).

⁷⁰ Patricia R. Recupero, Clinical Practice Guidelines as Learned Treatises: Understanding Their Use as Evidence in the Courtroom, 36 J. ACAD. PSYCHIATRY L. 290, 290 (2008).

⁷¹ Peter Moffett & Gregory Moore, *The Standard of Care: Legal History and Definitions: The Bad and Good News*, 12 W. J. EMERGENCY MED. 109, 111 (2011).

⁷² *Id.* at 110-11.

⁷³ HEALTH STANDARDS, *supra* note 40, at 36-37.

framework for long-duration space missions.⁷⁴ Current standards exist only for low-earth orbit.⁷⁵ Human spaceflight benefits from staying near the Earth because the supply (specifically mass and volume of the medical kits and medications) needs are low, ground communication is immediate, and evacuation—while difficult—remains a possibility. For the ISS, “the standard of care . . . is to support the crew 24/7 from Mission Control and to stabilize [and] transport an astronaut to Earth for definitive medical care.”⁷⁶ If an emergency occurs, the flight surgeons are available for consultation and, if needed, can guide a non-physician Crew Medical Officer or crew member through treatment processes via ground to space communications.⁷⁷ The ISS has a medical checklist onboard, in both Russian and English, that details common medical procedures astronauts may need to perform.⁷⁸

The 24/7 consultation and guidance model for the ISS is set up specifically for low-earth orbit.⁷⁹ Even the Apollo astronauts had ground control available at all times.⁸⁰ Maximum communication time between the Moon and ground control is about one second, which allows for continuous monitoring of astronaut health and expert

⁷⁴ See generally Gregory E. Stewart & Laura Drudi, *Medical Education for Exploration-Class Missions: NASA Aerospace Medicine Elective at the Kennedy Space Center*, 13 MCGILL J. MED. 55, 55 (2011) (stating that “there is no protocol for maintaining medical skills during a long duration mission”).

⁷⁵ See *id.*

⁷⁶ *Id.*

⁷⁷ See *id.*

⁷⁸ Int'l Space Station Integrated Medical Group (IMG) Medical Checklist, NAT'L AERONAUTICS & SPACE ADMIN. (Nov. 12, 2001), https://www.nasa.gov/centers/johnson/pdf/163533main_ISS_Med_CL.pdf. See also Letter from Jessica Cordero, FOIA Officer, Johnson Space Ctr., Nat'l Aeronautics & Space Admin., dated Mar. 14, 2016 transmitting documents, http://www.governmentattic.org/19docs/NASA-ISSmedicalEmergManual_2016.pdf (last visited Sept. 8, 2019).

⁷⁹ See generally Stewart & Drudi, *supra* note 74, at 55.

⁸⁰ See generally Transcript of Technical Air-to-Ground Voice Transmission (GOSS NET 1) from Apollo 11 Mission, NAT'L AERONAUTICS & SPACE ADMIN., https://www.hq.nasa.gov/alsj/a11/a11transcript_tech.html (evidencing that the radio contact between mission control and the spacecraft was constant throughout the mission, despite occasional blackouts from radiation interference, misaligned antennas on the spacecraft, or when the spacecraft went around the dark side of the moon).

medical advice on demand.⁸¹ Yet as missions develop farther into deep space, a low-earth orbit model will no longer be sufficient.

The constraint of requiring a completely self-sufficient spacecraft is daunting. While self-sufficient missions, such as the Apollo and Skylab missions, have been conducted in the past, the current spaceflight model has only limited applicability to an exploration-class mission. The spacecraft used in an exploration-class mission cannot turn around until it reaches its destination and will require all supplies and consumables to be loaded at the mission's start.⁸² Yet successful exploration missions are not without historical precedent. For example, exploration missions to inhospitable areas of Earth, such as Ernest Shackleton's expedition to the Antarctic in 1915, have proven successful.⁸³ However, the emergency medical needs of long-duration space missions require considerations different from those currently in use.

The standard of care onboard a Mars spacecraft will have to consider the above variables of supply and point-of-care treatment. Because of its long-duration nature, something as simple of "the proximity of the toilet may be important."⁸⁴ Within the self-contained spacecraft, there should be an area either dedicated or able to be quickly converted to a medical area. In addition, "certain core medical diagnostic, imaging, and laboratory equipment should also be present," so that the spacecraft can properly address an onboard emergency.⁸⁵ Ensuring proper equipment for medical treatment will become important, especially as new technologies become available. For example, a compact Magnetic Resonance Imaging machine has already been developed, and it can potentially be used on future

⁸¹ Royce W. Hawkings & John F. Zieglschmid, *SP-368 Biomedical Results of Apollo, Chapter 1: Clinical Aspects of Crew Health*, NAT'L AERONAUTICS & SPACE ADMIN., <https://history.nasa.gov/SP-368/s2ch1.htm> (last visited Apr. 16, 2018).

⁸² See *How Long Would a Trip to Mars Take?*, *supra* note 26.

⁸³ See ALFRED LANSING, *ENDURANCE: SHACKLETON'S INCREDIBLE VOYAGE* (Basic Books 2015).

⁸⁴ Summers et al., *supra* note 18, at 181.

⁸⁵ *Id.*

spaceflights.⁸⁶ Critically, the current standard of thinking both for use of therapeutic medications and for general treatment is based on the “concept of resuscitation, stabilization, and early evacuation.”⁸⁷ In adapting the current standard to long-duration flights, a revised standard should remove early evacuation and replace it with treatment and rehabilitation. Packing as much medical capability as possible into the spacecraft will reduce the risk of an emergency event leading to negative outcomes for crew members, even if it cannot completely eliminate the risk.

Realistically, it is difficult to imagine that these types of missions will have anything close to a fully equipped medical suite. Mass limitations will force tradeoffs for medical capability. Hospitals are sectioned into departments, each equipped to deal with a large variety of conditions requiring either general or specialty treatment. For example, if a patient presents to the emergency room and is found to have sepsis (a blood infection), then that patient is admitted to the general ward of the hospital or its intensive care unit, depending on the severity of the problem.

1. Sepsis: Illustrating the Need for a Change to the Standard of Care

Sepsis⁸⁸ is a telling example of the possible complications that could arise during a mission and how those complications would be addressed within the confines of spaceflight medical management in comparison to standard medical management. If an astronaut developed sepsis, this would require a different protocol than the standard model. Sepsis is a life-threatening emergency that can result

⁸⁶ Tereza Pultarova, *Canadian Researchers Developed a Body Scanner Suitable for ISS*, SPACE SAFETY MAGAZINE, (Sept. 2012), <http://www.spacesafetymagazine.com/spaceflight/space-medicine/canadian-researchers-developed-body-scanner-suitable-iss/>.

⁸⁷ Summers et al., *supra* note 18, at 181.

⁸⁸ See *Protocols & Checklists*, SURVIVING SEPSIS CAMPAIGN, SOC’Y OF CRITICAL CARE MED., <http://survivingsepsis.org/Resources/Pages/Protocols-and-Checklists.aspx> (last visited Sept. 8, 2019); COOKEVILLE REGIONAL MEDICAL CENTER, *Form 112-PRN, Severe Sepsis/Septic Shock Clinical Pathway*, <http://survivingsepsis.org/SiteCollectionDocuments/Protocols-Sepsis-Clinical-Pathway-Cookeville-Regional-Medical-Center.pdf> (last visited Feb. 9, 2019); STONY BROOK MEDICINE, *Severe Sepsis/Septic Shock Recognition and Treatment Protocols* (Aug. 9, 2013), <http://survivingsepsis.org/SiteCollectionDocuments/Protocols-Sepsis-Treatment-Stony-Brook.pdf>.

in death if the patient is not treated timely.⁸⁹ To illustrate how treatment would differ in space, consider the following hypothetical.

Astronaut Legstrong is on a long-duration mission with Astronaut Baldrin, the Crew Medical Officer. Legstrong is conducting routine maintenance cleaning some of the air filtration system when he cuts himself on a sharp corner. Legstrong does not think the cut is deep, so he opens the crew medical kit and applies a bandage to the area. Despite the fact that Legstrong knows that the air filtration system is dirty, he makes a weak attempt to locate the antibiotic ointment he knows he should use, but it is buried too deep in the overpacked medical kit. Since he's on a tight schedule, Legstrong does not search for long. Legstrong also does not see Dr. Baldrin because (1) the cut seems minor and (2) Dr. Baldrin has her own demanding schedule for the day. Sometime after the incident, Legstrong begins feeling feverish and dizzy, and he is unable to keep up with his demanding maintenance schedule. He asks Dr. Baldrin to come check up on him.

Dr. Baldrin must rule out sepsis, so she checks Legstrong's lactate level, which is easily done with a blood sample and a handheld machine. Baldrin notices that Legstrong's lactate level is much higher than what is normal. She also notices Legstrong's cut from earlier in the day now presents qualities of an infected wound and his blood pressure is low. At this point, if Dr. Baldrin were on Earth working in the emergency department, she would order blood cultures to determine if Legstrong has sepsis. If the test results came back indicating that Legstrong had a blood infection, the first line of treatment would be to start him on antibiotics.

However, Dr. Baldrin knows that her supply of antibiotics on board is limited, and the spacecraft is only halfway to Mars. Legstrong's lactate level is high, but without a way to process blood cultures onboard, Dr. Baldrin must rely on her best clinical judgement to determine the next steps in treating Legstrong. Baldrin must weigh the cost of using the onboard intravenous antibiotics now to treat Legstrong against more serious complications that could arise if Legstrong is not properly treated. Baldrin knows that on Earth, the standard of care would require her admit Legstrong to the hospital's

⁸⁹ *Sepsis*, MAYO CLINIC (Nov. 16, 2018), <https://www.mayoclinic.org/diseases-conditions/sepsis/symptoms-causes/syc-20351214>.

general acute care floor or its intensive care unit for intravenous antibiotics. Sepsis is not an easy problem to treat, and ensuring a patient is free from infection is a resource-intensive process.

One thing is clear: Legstrong will not get better without medical intervention. Dr. Baldrin begins giving Legstrong antibiotics. From here, two scenarios can possibly occur. First, because sepsis management is difficult, it will take at least a day—maybe up to a week—for Legstrong to recover. If Legstrong recovers in the first scenario, then the mission can still proceed as planned. The onboard antibiotics resources would have been used for their intended purpose, even if the medical resources would then be depleted leaving less available for an astronaut who may require antibiotics in the future. However, *not* treating Legstrong when the resources were available to attempt treatment would be unethical.

The second scenario that could occur is that Legstrong's condition could deteriorate. If an astronaut is sick or injured beyond the rehabilitation capabilities of the spacecraft medical suite and Crew Medical Officer but the astronaut could otherwise be kept alive through continuous application of medication or other treatment, then palliative care may need to be considered. ExMC researchers explain that tradeoff considerations will need to be weighed in these circumstances:

Ultimately, there may be instances where protecting the health of one crewmember could mean increasing the risk of harm to the other crew due to resource sacrifices. As a result, an ethical framework for exploration medical care will have to include not only clinical ethics directed at the care of each individual, but also the implications of decisions on the well-being of the entire crew.⁹⁰

If Legstrong does not recover soon, Dr. Baldrin will eventually be forced to decide whether she should continue to use the crew's supply of limited resources or withdraw care. At this point, the defined standard of care becomes important. The astronauts on this mission will have received training on the dangers associated with undertaking their mission. They will understand before the mission

⁹⁰ NAT'L AEROSPACE & SPACE ADMIN., EVIDENCE REPORT: RISK OF ADVERSE HEALTH OUTCOMES & DECREMENTS IN PERFORMANCE DUE TO IN-FLIGHT MEDICAL CONDITIONS 14 (2017), <https://humanresearchroadmap.nasa.gov/Evidence/reports/Medical.pdf>.

launches that the level of care they would otherwise receive on Earth is impossible to attain in space. In short, the standard of care in space is necessarily lower than that of Earth.

NASA has never shied away from informing their astronauts of the dangers of spaceflight. Astronauts are well-educated about the risks of their profession. NASA's current ethical framework for spaceflight is developed from committee recommendations compiled in a report, *Health Standards for Long Duration and Exploration Space Flight*.⁹¹ Recommendation 3 is salient for a standard of care discussion:

Recommendation 3: Implement Ethics Responsibilities NASA should adopt policies or processes that formally recognize the following ethics responsibilities related to health standards for long duration and exploration spaceflights: [1] Fully inform astronauts about the risks of long duration and exploration spaceflights and make certain that the informed decision-making process is adequate and appropriate.⁹²

Recommendation 3's list goes on beyond this. As best as can be estimated through NASA's knowledge and risk-management practices, astronauts know the personal consequences of signing up for a long-duration—that it could mean the death of a crewmate to prevent increasing risk for the rest of the crew and the mission.

Ultimately, it is important to accept the inherent risk of medical care in space travel, the ethical dilemmas of associated with this care in a resource-limited environment, and the likelihood of death occurring during a deep-space mission. The reality is that—with or without medical care—one day an astronaut will die in space. In light of this reality, emergency medical care must be considered in the context of its effect on the life of the entire crew, not the life of a single astronaut. When to enact palliative care, along with the opinions of the crew that must make the decision, should be integrated into the medical model.

⁹¹ *HEALTH STANDARDS*, *supra* note 40.

⁹² *Id.*

2. Ethical Considerations in Creating Long-Duration Mission Standard of Care

One special ethical consideration that differs between low-earth orbit missions and long-duration mission is that for a long-duration mission, astronauts may be required to undergo prophylactic surgery. The gallbladder and the appendix for astronauts have historically been primary infection risks.⁹³ Appendicitis⁹⁴ was suspected in two cosmonauts during the Russian Salyut missions.⁹⁵ In the end, the cosmonauts were diagnosed with ureterolithiasis and prostatitis, and the prostatitis case was evacuated.⁹⁶ This intervention was possible because of Salyut's low orbit around the Earth. In dangerous Earth-based missions, such as those in Antarctica, medical care can be similarly limited and may require evacuation. As an example, the risks of appendicitis at an Antarctic base are "reported to be as high as 43 per 1 million person-days The risk of 1 case every 10.6 years (9.4%/yr) is substantially higher than the 1 case every 125 years (0.8%/yr) calculated for a 6-member crew."⁹⁷ While data is known about the risks of appendicitis in Antarctica, similar data is not currently available for spaceflight risks.⁹⁸

Another example is cholecystitis.⁹⁹ The risk of contracting cholecystitis during spaceflight is unknown. Research shows that the illness affects 10-20% of the international population per year, with "risk of progression to symptomatic disease . . . about 1%-4% per year."¹⁰⁰ Prophylactic cholecystectomy is currently advocated for

⁹³ Chad G. Ball et al., *Prophylactic Surgery Prior to Extended-Duration Spaceflight: Is the Benefit Worth the Risk?*, 55 CAN. J. SURGERY 125, 126 (2012).

⁹⁴ Appendicitis is an inflammation of the appendix. It is a medical emergency that requires surgical removal of the appendix, but it can sometimes be treated with antibiotics if surgery is not an option. *Id.*

⁹⁵ *Id.*

⁹⁶ *Id.*

⁹⁷ *Id.*

⁹⁸ *Id.*

⁹⁹ Cholecystitis is an inflammation of the gallbladder. Depending on the type of cholecystitis with which a patient presents, surgical removal of the gallbladder may be required. Doctors may elect to surgically remove the gallbladder. *Id.* at 127.

¹⁰⁰ *Id.*

patients with increased risks of gallstones.¹⁰¹ Terrestrially, both cholecystitis and appendicitis can be treated surgically.¹⁰² Surgery in space, however, is riskier. Sometimes, an operation may not be the best option: “the current [U.S.] Navy protocol for appendicitis has a 75% success rate with [intravenous] antibiotics.”¹⁰³ While this treatment may work well at sea, naval vessels have the benefit of being resupplied. Once locked into a long-duration mission trajectory, a spacecraft does not. Given “the limited number of candidates and continually advancing minimally invasive surgery options, the ease and safety of surgical prophylaxis currently appears to outweigh the logistics of treating either acute appendicitis or cholecystitis during extended-duration space flight.”¹⁰⁴ Prophylactic surgery essentially reduces risk, especially when there is no guarantee of an in-flight surgical suite capable of conducting appendectomies or cholecystectomies.

However, NASA’s current line of thinking suggests that astronauts should not go forward with a prophylactic appendectomy due to the risk of small bowel obstruction, and the ethical concerns it raises.¹⁰⁵ Consider this hypothetical situation: an astronaut candidate is selected into the astronaut corps; prophylactic appendectomy is necessary for a spaceflight rating, so the astronaut candidate undergoes the surgery.¹⁰⁶ Later, the candidate is forced to fail out of training because of complications arising from that appendectomy.¹⁰⁷ Was it ethical to require the candidate to undergo the surgery in the first place?¹⁰⁸ Even though procedures like appendectomies are relatively common to a general surgeon, every surgery carries an aspect of risk with it. Moreover, the risk of appendicitis during

¹⁰¹ *Id.* at 127–28.

¹⁰² See generally *id.* (discussing the general treatment for cholecystitis and appendicitis).

¹⁰³ Stewart et al., *supra* note 13, at 52.

¹⁰⁴ See Ball et al., *supra* note 94, at 129.

¹⁰⁵ *Id.*

¹⁰⁶ *Id.* at 128–29.

¹⁰⁷ See *id.*

¹⁰⁸ See *id.*

spaceflight may be lower than the risk associated with a terrestrial appendectomy.¹⁰⁹

C. Astronaut Medical Training: Inherent Limitations in the Current Model

Missions under 210 days in length do not require a physician as part of the flight crew.¹¹⁰ Currently, the physicians for the astronauts (crew flight surgeons) are all based in Mission Control. Physicians may fly as part of an astronaut crew and may be designated the Crew Medical Officer (“CMO”), but their astronaut responsibilities must come first. Because medical care is not the primary focus of a specific astronaut, this creates a gap in the move toward a long-duration model. All astronauts “receive basic medical training, including space physiology, toxicology, CPR, first aid, [Crew Healthcare Systems Hardware], and psychological training,”¹¹¹ but only some astronauts are trained as the CMOs.¹¹² CMOs receive 40–70 hours of medical training before launch in order to function as the on-board medical providers, dealing with both medical research and actual medical events that may occur.¹¹³ Specifically, they “receive additional hands-on training in diagnostic and therapeutic techniques, operating procedures for in-flight medical hardware, dental procedures, ACLS, and clinical psychology.”¹¹⁴

Training a CMO to the standard of a nurse or physician is infeasible during astronaut training.¹¹⁵ However, an entire crew will train on at least one simulated medical emergency, which allows them

¹⁰⁹ *Id.* at 126.

¹¹⁰ Michele L. McCarroll et al., *Medical Judgement Analogue Studies with Applications to Spaceflight Crew Medical Officer*, 3 BMJ SIMULATION & TECH. ENHANCED LEARNING 163 (2017).

¹¹¹ NAT’L AERONAUTICS & SPACE ADMIN., INT’L SPACE STATION PROGRAM, INT’L SPACE STATION MEDICAL OPERATIONS REQUIREMENTS DOCUMENTS – REVISION B (May 2003), [hereinafter ISS MEDICAL OPERATIONS REQUIREMENTS] (summarizing section 4.3.4 through 4.3.4.3).

¹¹² *Flight Surgeons*, NAT’L AERONAUTICS & SPACE ADMIN. (Feb. 24, 2015), <https://www.nasa.gov/content/flight-surgeons>.

¹¹³ *Int’l Space Station Medical Monitoring*, NAT’L AERONAUTICS & SPACE ADMIN. (Dec. 28, 2017), https://www.nasa.gov/mission_pages/station/research/experiments/1025.html.

¹¹⁴ ISS MEDICAL OPERATIONS REQUIREMENTS, *supra* note 83 (quoting section 7.2.1).

¹¹⁵ *Id.*

some familiarization with the interaction between the CMO and crew flight surgeons, and their respective roles.¹¹⁶ The current system works because crews have instantaneous communication with physicians on the ground, including constant private medical conferences between the astronauts and the crew flight surgeons.¹¹⁷

D. Emergency Medicine as the Baseline for a New Standard of Care for Long-Duration Spaceflight

NASA currently recognizes the need for physician-astronauts. In the NASA technical standards for crew health, Standard 4.1.1.6 (Level of Care Five) states “the training and caliber of the caregiver shall be at the physician level.”¹¹⁸ Despite this heightened caregiver status, the standard continues, “consumables and survival of the remaining crew members dictate what resources can be expended on critical care for the ill or injured crew member.”¹¹⁹ The training required to become a physician is long and arduous, and the 40–70 hours of training that non-physician CMOs currently receive is insufficient for a long-duration mission. A recent study on CMO medical decision-making verified that there are “significant differences in medical judgement and simulation performance outcomes in spaceflight crew analogue groups of non-physician CMOs versus physician CMOs.”¹²⁰ The easiest solution to overcome this discrepancy is to require that a physician be the CMO for long-duration missions.

This CMO study had several limitations.¹²¹ Most important for this article is that “the physician CMO analogue group demonstrated similar distress when faced with a medical scenario outside their practice specialty.”¹²² While the CMO study did not define the specialty of the physicians who participated, there is one specialty that

¹¹⁶ *Id.*

¹¹⁷ *Flight Surgeons*, *supra* note 110.

¹¹⁸ NAT'L AERONAUTICS & SPACE ADMIN., NASA-STD-3001, SPACE FLIGHT HUMAN SYS. STANDARD VOLUME 1: CREW HEALTH (2007) (summarizing section 4.1.1.6.4).

¹¹⁹ *Id.*

¹²⁰ McCarroll et al., *supra* note 80, at 165–66.

¹²¹ See *id.* at 165–67.

¹²² *Id.* at 167.

covers many aspects of medicine: emergency medicine. Emergency physicians are generalists who must deal with different parts of anatomy and physiology every day, serving as a jack-of-all-trades in the medical community. Specific qualities make them more useful to a long-duration mission: “[they are] used to functioning in a team, handling stressful and unexpected situations, improvising when necessary, and . . . [communicating] effectively to a vast array of specialists.”¹²³ Because of the generalist status, emergency physicians “have a broad knowledge base, are proficient in basic surgical skills, and are competent in the management of critically ill and injured.”¹²⁴ Some scholars even espouse the benefits of a fellowship in wilderness medicine for astronauts, in keeping with the improvisational, isolation, and preventative aspects of such training.¹²⁵ The McCarroll-led CMO study agrees, finding that “attending physicians in the field of emergency medicine and general surgery displayed the most composure and the highest [Medical Judgement Metric] scores during these Exploration Medical Conditions List specific scenarios.”¹²⁶ Thus, these studies show that emergency medicine experience should be considered an advantage when NASA is selecting physician astronauts for long-duration missions.

The emergency medicine model only stretches so far. Contrary to the typical unknown patient in an emergency room, astronaut physicians will have an intimate knowledge of their crew. The long-duration CMO will likely have access to her fellow astronaut’s entire medical history, as well as physical and mental performance indicators. A major function of an emergency physician is to evaluate a patient and determine whether they can be safely discharged or admitted to the hospital for further care.¹²⁷ If the patient is admitted, the emergency physician’s responsibility to the patient essentially ends when the patient is admitted.¹²⁸ Emergency physicians may have knowledge of medical management for patients in an ICU, but they

¹²³ Kuypers, *supra* note 36, at 446.

¹²⁴ *Id.*

¹²⁵ *Id.* at 447.

¹²⁶ McCarroll et al., *supra* note 80, at 12.

¹²⁷ Telephone interview with William Sproule M.D., Envision Physician Services (Jan. 10, 2019).

¹²⁸ *Id.*

are not necessarily trained in internal medicine beyond the rotations completed in medical school.¹²⁹ It is possible for an emergency physician to also complete an intensivist fellowship, which certifies her to work in the ICU.¹³⁰ Emergency medicine also has training in some basic surgical procedures as well, such as abscess drainage,¹³¹ but further experience with procedures (e.g., appendectomies) would be useful during a long-duration space mission. The ideal CMO physician would be a generalist with further training in wilderness medicine, internal medicine/critical care medicine, and some further surgical training, in addition to the space medicine that they are already required to know. Having knowledge or training in management of a patient beyond the emergency room will only serve to benefit the whole of the crew.

III. EXAMPLES OF HIGH ACUITY MEDICAL EMERGENCIES FOR WHICH EMERGENCY MEDICINE IS SPECIALIZED

Emergency rooms are chaotic. The staff never know what kinds of complaints they will see during their shift and must be prepared for any possible medical complaint—from common cold to car accident. Medical issues in space could develop at any time, similarly necessitating a ready-for-anything prepared crew and supply of equipment. Training in emergency medicine shares some similarities with medical conditions that could be encountered during spaceflight.

A. Trauma

Historically, only minor trauma has occurred in spaceflight.¹³² If any situation were to occur on the ISS requiring trauma surgery, it would cause an evacuation. Luckily for long-duration missions, some procedures have already proven viable:

¹²⁹ *Id.*

¹³⁰ *Id.*

¹³¹ *Id.*

¹³² Kirkpatrick et al., *Severe Traumatic Injury During Long Duration Spaceflight: Light Years Beyond ATLS*, 3 J. TRAUMA MGMT. & OUTCOMES 2 (2009).

The standard trauma life support (ATLS) procedures have been demonstrated to be feasible in microgravity, using animal models and standard equipment manifested on the ISS. Procedures that were not significantly more technically difficult to perform in a 1 g environment included: intravenous fluid infusion, Foley catheter drainage, laceration closure, artificial endotracheal ventilation, chest tube insertion and suction, percutaneous tracheostomy, and cricothyrotomy, with the addition of transmuscular anesthesia, dissection, hemostasis, and wound closure.¹³³

Indeed, “[a] cardinal finding of the integrated space surgery research is that seemingly any terrestrial procedure can be performed in weightlessness, if the correct equipment is provided, and operator, subject, and tools are adequately restrained.”¹³⁴

Microgravity is actually beneficial for locating wounds and some surgical procedures.¹³⁵ Blood has high surface tension, and it stays close to the wound.¹³⁶ While moving some organs to achieve traditional visual landmarks is more difficult, contamination of the surgical and surrounding environment is lessened due to this surface tension.¹³⁷ Surgery itself can be performed in specialized chambers that are placed over the patient.¹³⁸ New developments include the creation of even smaller hermetically sealed chambers placed directly over the surgical area.¹³⁹ Disposal also becomes an issue in an enclosed environment. Making sure proper disposal procedures are in place will prevent contamination of the spacecraft environment.

For all intents and purposes, then, actual surgery is achievable during a long-duration environment. Supporting surgical functions for trauma events will require some adaptation but are as workable as surgery.

¹³³ Stewart et al., *supra* note 13, at 52.

¹³⁴ Laura Drudi et al., *Surgery in Space: Where are we at now?*, 79 ACTA ASTRONAUTICA, 61, 63 (2012).

¹³⁵ Mark R. Campbell et al., *Surgical Bleeding in Microgravity*, 177 SURGERY, GYNECOLOGY & OBSTETRICS 121, 125 (1993).

¹³⁶ *Id.* at 125.

¹³⁷ *Id.*

¹³⁸ Summers et al., *supra* note 18, at 181.

¹³⁹ See generally Jennifer A. Hayden et al., Technical Note, *A Hermetically Sealed, Fluid-Filled Surgical Enclosure for Microgravity*, 84 AVIATION, SPACE, & ENVT. MED., no. 12, 2013.

B. Anesthesia

Anesthesia requires a few more restrictions. The microgravity environment means that gaseous anesthesia cannot be used due to the risk of contaminating the closed environment. Similarly, “spinal anesthesia also poses a problem . . . as the anesthetic may be distributed differently secondary to the cephalad shift that occurs in microgravity.”¹⁴⁰ Therefore, intravenous anesthetics must be used. Using intravenous anesthetics decreases the training required for administering anesthesia because “unassisted personnel with minimal medical training and familiarization with the equipment may be able to perform advanced medical care in a safe and efficient manner”¹⁴¹—such as administer intravenous anesthesia. Given that every astronaut receives basic medical training, providing anesthesia under the direction of the CMO is a feasible task. Rather, the limiting factor may be supply. If a patient would endanger the mission by requiring constant or long-term anesthesia, it may be time to consider alternatives to intervention, such as withdraw of medical care.

C. Cardiac Emergencies

Microgravity does not detract from dealing with cardiac emergencies. Rather, the considerations are similar in that the patient, healthcare provider, and equipment must all be restrained. To conduct cardio-pulmonary resuscitation, the provider must use “an unconventional vertical-inverted positioning with the CPR provider placing his feet on the ceiling as a brace for counterforce,” allowing force to be applied to the patient.¹⁴² Physiological deterioration of the heart in microgravity must also be considered when delivering medication. The medication itself may have unpredictable effects in microgravity, which is difficult to test due to the nature of epinephrine and other cardiac emergency medications.¹⁴³ Arrhythmias are also

¹⁴⁰ Drudi et al., *supra* note 135, at 63.

¹⁴¹ Matthieu Komorowski & Sarah Fleming, *Intubation After Rapid Sequence Induction Performed by Non-Medical Personnel During Space Exploration Mission: A Simulation Pilot Study in a Mars Analogue Environment*, 4 EXTREME PHYSIOLOGY & MED., no. 19, 2015, at 1.

¹⁴² Summers et al., *supra* note 18, at 182.

¹⁴³ *Id.*

common in space; instances of tachycardia have occurred as well.¹⁴⁴ Extra Vehicular Activities (i.e., spacewalks) are particularly risky due to pressure differences, requirements for long endurance with a deconditioned cardiac system, and constant physical activity. Cardiac events may become more common as the heart deconditions with longer length of stays in space.

In effect, there is minimal difference between the type of trauma, anesthesia, and cardiac conditions in space and on the ground. Dealing with medical emergencies during spaceflight involves extra considerations, but it does not necessitate the development of entirely new treatment methods. The extra considerations include spacecraft contamination, proper disposal of medical waste, and limitations on technological diagnostic capability. The most difficult decisions concern the use of resources to treat long-term conditions, such as sepsis, or the long-term management of illnesses that may develop during the journey.

CONCLUSION

Establishing a new medical framework in space will be necessary when NASA and other space agencies reach beyond low-earth orbit. While the medical procedures themselves do not require significant theoretical alteration, practically testing and verifying these procedures remains a daunting task. The research into space medicine is still in an early stage and will evolve as the mission becomes more focused and further research is conducted.

NASA must shift from the current evacuation model to a new one that better addresses the realities of a long-duration flight. This shift is already underway as researchers tackle the problems of limited supply, communications lag, and the necessity of a self-contained spacecraft. The closer we get to launching a long-duration flight, the more important these considerations will become. While it is difficult to design a medical framework around a long-duration mission that does not yet have definitive objectives, it is still possible to start

¹⁴⁴ Janice M. Fritsch-Yelle et al., *An Episode of Ventricular Tachycardia During Long-Duration Spaceflight*, 81 AM. J. CARDIOLOGY 1391, 1391 (1998).

planning for potential long-duration missions, including a Lunar base or Mars orbit mission.

It is clear that terrestrial models for standard of care will not apply in space, especially in regard to ethical standards. Included in this standard of care must be conditions that not only will allow CMOs to be trained in the practical aspect of their job but also will enable them to make the hard decisions that come with exploring in a self-contained vehicle at the mercy of physics. These decisions could include withdrawing care earlier than what is standard on Earth for conditions that require resource-intensive treatment. Key to creating this standard is the ethical consideration that resource decisions could take away from future protection from other members of the crew. Educating astronauts on these risks is fundamental to ensure they can make educated decisions when deciding whether to participate in a long-duration mission.

Finally, physicians trained in emergency medicine already possess many of the skills to deal with many aspects of space medicine. Their expertise will prove advantageous for long-duration missions to the Moon, Mars, and beyond because of the similarities between the emergency room setting and the realities of how medical treatment and management will be handled during spaceflight. The skillset emergency physicians provide is currently the closest to the needed skills for long-duration missions.

Our existing history with space mission has taught us that space is an environment where planning and preparation are key to success. The space medicine community must begin establishing a new medical framework for long-duration missions with these considerations in mind. While the final standards established will ultimately differ from any possible terrestrial model, the emergency medicine model provides a solid foundation from which to build. Constructing a framework now will allow future research to focus on deepening our knowledge of space medicine in order to ensure we continue with a medical structure that will save lives in future expeditions.