Student Scholarship Submission

Medical, Technological, and Ethical Challenges for the Initial Expedition to Mars

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Abstract

For more than a decade, the National Aeronautics and Space Administration (NASA) has been actively pursuing the goal of landing humans on Mars. This spectacular mission has been inspired by the search for extraterrestrial life, advancing planetology, and the potential for human habitation. Since landing a man on the moon in 1969, there has been enormous pride associated with space travel in American society. Human spaceflight and exploration should continue to be cultivated in its citizens, government, academic pursuits and commercial endeavors.

NASA's three-phase plan for landing humans on Mars effectively addresses the complexities of deep space exploration by leveraging past lessons and fostering collaborations. Their iterative Moon to Mars Architecture ensures continuous technological advancements, positioning them well to achieve their ambitious goal. Given the current uncertainties of Space Launch System (SLS) viability, however, the availability and affordability of commercial contributions is of increasing significance. This paper explores the medical, technological, and ethical challenges associated with the initial human mission from a lunar outpost to Mars. Additionally, it examines the critical requirements for successfully initiating research and development activities on the Martian surface.

Keywords: NASA, Mars, medical, ethical, Outer space, space travel, technology

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Desafíos médicos, tecnológicos y éticos para la expedición inicial a Marte

Resumen

Durante más de una década, la Administración Nacional de Aeronáutica y del Espacio (NASA) ha perseguido activamente el objetivo de llevar humanos a Marte. Esta espectacular misión se ha inspirado en la búsqueda de vida extraterrestre, el avance de la planetología y el potencial de asentamiento humano. Desde que el hombre pisó la Luna en 1969, la sociedad estadounidense ha sentido un enorme orgullo por los viajes espaciales. Los vuelos espaciales tripulados y la exploración deben seguir siendo un objetivo prioritario para la ciudadanía, el gobierno, las actividades académicas y las iniciativas comerciales.

El plan de tres fases de la NASA para el aterrizaje humano en Marte aborda eficazmente las complejidades de la exploración del espacio profundo, aprovechando las lecciones aprendidas y fomentando la colaboración. Su arquitectura iterativa de la Luna a Marte garantiza avances tecnológicos continuos, lo que la posiciona bien para alcanzar su ambicioso objetivo. Sin embargo, dada la incertidumbre actual sobre la viabilidad del Sistema de Lanzamiento Espacial (SLS), la disponibilidad y asequibilidad de contribuciones comerciales cobra cada vez mayor importancia. Este artículo explora los desafíos médicos, tecnológicos y éticos asociados con la misión humana inicial desde un puesto avanzado lunar a Marte. Además, examina los requisitos críticos para iniciar con éxito las actividades de investigación y desarrollo en la superficie marciana.

Palabras clave: NASA, Marte, medicina, ética, espacio exterior, viajes espaciales, tecnología

首次火星探测任务面临的医学、技术和伦理挑战

摘要

十多年来，美国国家航空航天局（NASA）一直积极致力于实现载人登陆火星的目标。这项宏伟计划源于对地外生命的探索、行星学的发展以及人类在火星上居住的潜力。自1969年人类成功登月以来，太空旅行一直是美国社会引以为豪的事业。载人航天和探索应该继续在美国公民、政府、学术界和商业领域得到大力发展。

NASA的载人火星登陆三阶段计划通过借鉴以往经验和促进合作，有效应对了深空探索的复杂性。其迭代式的“月球到火星架构”确保了技术的持续进步，使其能够更好地实现这一宏伟目标。然而，鉴于目前太空发射系统(SLS)可行性的不确定性，商业贡献的可用性和可负担性变得日益重要。本文探讨了从月球前哨站到火星的首次载人任务所面临的医学、技术和伦理挑战。此外，本文还探讨了“在火星表面成功开展研发活动”一事的关键要求。

关键词：美国国家航空航天局(NASA)，火星，医学，伦理，外太空，太空旅行，技术

Introduction

Collaboration with international and U.S. companies will enable NASA to push past the lunar outpost and onto Mars. This exploration to Mars is not the terminus, but an agent to permanent human deep space occupation. President Obama formally directed the agency to reach for human exploration of the Red Planet by the 2030s (National Aeronautics and Space Administration Authorization Act of 2010). Multiple collaborative partnerships have enabled success in the lunar outpost thus far: communicating a dedication to advancing scientific discoveries and commencement of the lunar economy. The capital investments in technology enable 52 crew members to reside on the Moon for two 5-year rotations. But this trial is intended to enable deep space exploration, and substantial investments are necessary to overcome the medical, technological, and ethical challenges faced today.

This paper will first examine the medical challenges that require further research. Space radiation is still the most formidable obstacle to human exploration. The omnipotence of ionized radiation from Solar Particle Events (SPE) and Galactic Cosmic Radiation (GCR) and the risks posed to biological systems are pertinent topics of study in the space community (Montesinos et al., 2021). Limitations of current shielding technology and nutritional understanding of immunity methods require further studies. Continually, there is technology needed to sustain humans on Mars for the intended 6 to 18 months stay. Life support systems and habitats require further development for this mission to be successful. The multi-faceted robotic deployment to the Red Planet ahead of the explorers will aid greatly in habitat manufacturing (Weisben et al., 1997). Finally, there are policies and procedures that need developing while ensuring adherence to the highest ethical standards. The realization of this daring journey will strengthen America's leadership both in space and back on Earth.

Methods

NASA's *Houston We Have a Podcast* Episode "Moon to Mars: Reviewing the Architecture" (Cheshier, 2024) was used to gather background data on the Architecture Concept review and efforts to take humans into deep space. APU's Tefry Library was utilized to find peer-reviewed, English references. Some of the MeSH terms used to search were spacecraft medical challenges, nanocomposites material space benefits, "US Space Force" ethics, NASA Mars architecture, and radiation countermeasures. Nicogossian et al. (2016) textbook and week 1-8 lesson plans from SPST619 were used for background knowledge and linked references explored. The works referenced were all published after 1997, but the majority from 2010s or more recent. Fair evidence came from two textbooks by McCoy and Kahn (2014) and Nicogossian et al (2016).

Results

From the combined extensive searches, over 14,000 papers were returned. Of this, 37 abstracts were read and filtered to inform this report. 14 peer-reviewed journal articles, 2 legal documents, 1 government publication, 2 reports, 4 .gov websites, 1 NASA podcast, 2 textbooks and 8 APU course SPST619 lesson plans are included in the references section. Life journal has a strong reputation and was awarded an impact factor of 3.2 from the MDPI in 2024. The summary of types of evidence can be seen below in Table 1.

Table 1. *Research and Citation Evaluation Summary*

Author/Date	Publication Type	Remarks	Strength of Evidence
Miranda et al., 2023	Peer reviewed journal article	Evaluates anecdotal evidence regarding multiple lunar explorer's experiences with dust and their issues. Primary and secondary effects from lunar dust are investigated and compared to Earth peer-reviewed studies.	Strong
Paul et al., 2022	Peer reviewed journal article	The first experiment to use samples from Apollo 11, 12, and 17, to show that the terrestrial model plant Arabidopsis thaliana germinates and grows in diverse lunar regolith. Further studies are required.	Strong

Weisbin et al., 1997	Peer reviewed journal article	A review of the role of robotics in space exploration for the four core applications areas.	Good
Stough & Nicogossian, 2006	Report	Medical policy discussion. Thesis from George Mason University.	Fair
Tanaka et al., 2017	Peer reviewed journal article	Microgravity effects on human subjects aboard ISS. Deconditioning and countermeasure suggestions.	Good
Rittweger et al., 2018	Peer reviewed journal article	Analysis of the Sarcolab pilot study into muscle adaptation of long-term spaceflight.	Good
Baiocco et al., 2020	Peer reviewed journal article	PERSEO ISS experiment with a water-filled torso garment to protect against radiation.	Strong
Montesinos et al., 2021	Peer reviewed journal article	Review of Space radiation countermeasures in planetary exploration applications.	Good
Basner et al., 2014	Peer reviewed journal article	Summary of the 520 day simulated Mars mission and the psychological considerations of isolation/confinement.	Good
Kim et al., 2024	Peer reviewed journal article	Review of astronaut personality traits which could mitigate crew interaction risks on a Mars mission.	Good
Bell, 2007	Peer reviewed journal article	Meta analysis of Deep-Level Composition Variables as Predictors of Team Performance, focused on psychology	Strong
NASA, 2015	Government publication	Laid out the strategies and long-term plan to send humans to Mars.	Fair

Pernigoni et al., 2024	Peer reviewed journal article	An experiment with self-healing polymers and nanocomposites where they examined the radiation shielding properties and compared them to typical metallic spacecraft materials.	Strong
Krichevsky, 2021	Peer reviewed journal article	Analysis of the development of artificial gravity for space biosphere environmental management. Introduces philosophical arguments for AG.	Strong

Note. This table shows the relevant sources used to inform this discussion. A summary of their methods is provided. The strength of evidence is based on sample size, research methods, limitations and inconsistencies in the cited works.

Discussion

NASA's three-phase plan for landing humans on Mars involves learning from past missions and collaborating with international, academic, and commercial partners. The first phase, Earth Reliant, included over two decades of experiments aboard the ISS and in isolated environments to prepare for lunar missions. This was followed by the Proving Ground phase, which focused on stable cislunar orbit and exploratory missions that confirmed capabilities for Mars. The final phase, Earth Independent, is when humans will land on Mars, building on the groundwork laid in previous stages.

Key challenges identified by NASA include transportation, working in space, and maintaining astronaut health. Significant technological innovations are necessary to address these demands, as outlined in the Moon to Mars Architecture blueprint. The agency conducts annual Architecture Concept Reviews to assess mission status and gather feedback, producing an updated *Architecture Definition Document* to identify technological gaps that academia and industry can help fill. NASA emphasizes the importance of partnerships and global collaboration in this endeavor.

Medical Considerations

Human interplanetary travel and subsequent habitation on Mars present a wide array of health challenges. The harsh and unforgiving environment of space is characterized by dangers such as microgravity, elevated radiation levels, ICEs, and an absence of atmosphere.

Prolonged exposure to microgravity is associated with health issues such as cardiovascular complications, bone density loss, muscular atrophy, and vestibular disorders (Montesinos et al., 2021; Nicogossian et al., 2016; Rittweger et al., 2018; Tanaka et al., 2016). Altered hydrostatic pressure in microgravity reduces heart stroke volume, impacting cardiovascular health (Tanaka et al., 2016). Rittweger et al. (2018) noted that changes in muscle architecture contribute to muscle weakness. The Sarcolab pilot study showed that astronaut B, who followed a stricter exercise regimen, maintained better muscle strength than astronaut A. Nutritional supplements like selenium and pharmacological interventions may help mitigate some negative health effects of interplanetary travel (Montesinos et al., 2021). The 2015 NASA Twins Study revealed mitochondrial dysregulation as a biological response to extended spaceflight (Krichevsky, 2021). To address microgravity's adverse effects, designing a spacecraft with artificial gravity is a key objective to be explored in the technology section.

Radiation is the prime health risk in spaceflight, with ionizing radiation being far more harmful than what humans are adapted to on Earth (non-ionizing). Ongoing research aims to find nutritional and pharmacological ways to reduce radiation damage. Non-invasive radiation dosimeters will be a mandatory part of the space traveler's uniform. Crew selection is vital, as genetic and biological predispositions yield varying radiation tolerances (Bourguignon et al., 2005; Nicogossian et al., 2016). While lowering radiation exposure limits can reduce costs, further ISS research is needed to confirm these limits. Furthermore, studies must differentiate between continuous and episodic exposure, as well as between high-energy and low-energy particles, which can have opposing effects on biological systems. NASA currently prioritizes astronaut safety through its ALARA (As-Low-As-Reasonably-Achievable) policy. Investigations into anti-radiation medications and genetic vaccines are ongoing, and NASA has used multi-vitamins and minerals in past missions to help mitigate negative radiation effects (Montesinos et al., 2021).

Mental and behavioral health is crucial for the Mars mission, as crew selection, training, and individual resilience will significantly impact success and safety (Kim et al., 2024). The Mars Society and NASA have invested decades in human performance data and ergonomic design, but a 520-day simulated Mars mission revealed that conflicts with mission control were five times more frequent than those among crew members (Basner et al., 2014). Effective communication and conflict resolution strategies will be essential, especially since the Mars team must maintain contact with the lunar outpost, which will serve as a liaison to Earth. Given the inevitable delays in communication, stable team dynamics are vital. Research conducted by Bell (2007) underscores the importance of morale in high-stakes environments. A sustainable work-rest cycle positively influences morale, which will be essential for the success of the approximately 2.5-year-long mission. Psychological preparedness is a critical component of medical readiness.

Technological Considerations

Technology will play a crucial role in the journey from the moon to Mars and back, particularly through the implementation of artificial gravity to offset the negative effects of microgravity on the human body. Countermeasures to microgravity and mandatory daily 2 hours exercise are only partially effective. Artificial gravity is costly but essential for long-duration flights (6-9 months) to ensure astronaut safety and health (Krichevsky, 2021). Research into reliable systems using centrifugal force or high-frequency vibrations is needed, while Mars's more favorable gravity (≈0.38 g) allows for the exclusion of artificial gravity in Martian outposts.

To combat radiation exposure, technological solutions like space suits and radiation shielding are vital (Nicogossian et al., 2016, pp. 43-46). Space suits are necessary for extravehicular activities (EVA), where decompression sickness is a risk. Additionally, the use of self-healing nanocomposites may increase durability and safety while simultaneously reducing weight (Pernigoni et al., 2024). Administrative measures such as aligning launch plans with solar cycle minimums is a low-cost way to decrease total crew radiation exposure.

Radiation protection methods can be categorized broadly into personal and vehicle protection. Personal protection examples include water-filled wearable suits for maneuverability, while vehicle protection involves shielding materials like water or hydrogen (Biacco et al., 2020). However, the Bremsstrahlung effect, which can increase radiation by 30%, must be considered in shielding design (Nicogossian, 2016). Bremsstrahlung translates to "braking radiation" in German and occurs when a high energy electron interacts with an atom's nucleus (i.e., impacts the metallic shield of spacecraft) result in the emission of electromagnetic radiation. Effective radiation shielding requires balancing time, cost, weight, and effectiveness. A hybrid approach of personal and vehicular protection is desirable.

Upon landing on Mars, robots will have prepared an underground habitat, minimizing manual labor for astronauts. Further funding is required to advance the artificial intelligence (AI) capabilities and energy storage of the robotic cadre project managers (Weisben et al., 1997). This habitat will offer radiation and dust protection, featuring four double airlock exits, dormitories, labs, a communal space, and a mess hall. Nuclear power will supply lighting and electrical systems, supplemented by solar panels, with additional funding needed for robotic maintenance to prevent dust-related issues, as seen with NASA's InSight rover in 2022.

Paul et al. (2022) propose using Mars to initiate in situ growth through a regolith matrix, while lunar regolith experiments have shown limited plant growth. Hydroponics will be prioritized on Mars, but establishing a research site for terrestrial agriculture is essential. Plants are crucial for long-term space habitation, as they provide food and oxygen, recycle water, and remove carbon dioxide.

Lunar dust poses significant challenges due to its abrasive and sharp nature. As humans are established on the moon with a semi-permanent presence, integrated dust mitigation strategies are vital for sustainable lunar architecture. Although Martian dust differs from lunar dust, advancements in understanding lunar dust toxicity and mitigation strategies can inform future operations on Mars (Miranda et al., 2023).

Ethical Considerations

The journey from the Moon to Mars raises significant ethical considerations, particularly regarding the governance and utilization of outer space. The Outer Space Treaty of 1967, like the Antarctic Treaty, established a framework for international cooperation in space. But competing political, military, commercial, and scientific interests complicate its application. Just as disregard for maritime agreements can harm shared oceans, violations of space treaties can have far-reaching consequences (*The American Journal of International Law*, 2020).

Leadership and crew composition will play a critical role in addressing these ethical challenges. While decisions will primarily be made democratically, a single mission commander will take control in emergencies. Medical policy formulation and advanced directives will be a particular notable ethical friction point. Informed consent and equitable access to medical treatment for the 10-person exploration crew to Mars will be mandatory. A code of conduct could be implemented for the travelers to promote a sense of community.

Additionally, ethical considerations regarding back contamination are paramount. Article IX of the Space Treaty mandates controls to prevent both forward and backward contamination, necessitating strategies such as dry heat sterilization of spacecraft components and robotic assembly in sterile conditions. Sample return missions, classified as Category 5, require stringent precautions, following guidelines from NASA's Astrobiology program and the Chief Health and Medical Officer (Nicogossian et al., 2016, p. 90). Paul et al. (2022) noted that back contamination concerns from early Apollo missions were addressed through isolation protocols for astronauts and medical staff, as well as intensive containment measures for lunar samples at the JSC Lunar Receiving Laboratory. These strategies included high-level biological containment boxes and detailed searches for extraterrestrial pathogens, underscoring the importance of ethical considerations in ensuring the safety and integrity of both space and Earth.

Conclusion

NASA's structured three-phase plan for traveling from a lunar outpost to Mars and back emphasizes a comprehensive strategy for addressing the complexities of deep space exploration. By applying lessons learned from previous missions and fostering collaborations across various sectors, NASA is effectively tackling significant challenges related to transportation, operational efficiency, and astronaut health. The iterative nature of NASA's *Moon to Mars Architecture*, along with regular assessments and updates, allows for the continuous integration of technological advancements into their mission framework.

As humanity embarks on long-term lunar living and interplanetary exploration, understanding the health risks associated with space travel becomes increasingly important. Challenges such as radiation, cardiovascular issues, and muscle degeneration necessitate effective solutions to ensure the well-being of astronauts and future Martian residents. The rise of commercial space travel further underscores the need for robust space medicine practices to protect both professional astronauts and civilian tourists. Balancing security with ethical responsibilities is vital to ensure that our actions in space promote peace and sustainability. With a clear roadmap in place, NASA is well-prepared to achieve its ambitious goal of landing humans on Mars.

Limitations and Bias

There are considerable research gaps to this Mars trip analysis, and they are further exacerbated by limited funding and shifting political goals. The three key challenges addressed above are limited by the current inability to perform extensive research in deep space. Significant knowledge gaps exist in space medicine and human health, particularly regarding long-term effects with novel stimuli like lunar dust exposure. With fewer than 3,000 people having been exposed to spaceflight, the data available cannot yet be considered statistically robust. Increased investment in comprehensive studies is crucial to improving safety and the probability of mission success.

Continually, there may be ethical challenges surrounding medical policy formation and the exploration of other ecosystems. Much of the existing clinical knowledge about radiobiological effects comes from terrestrial exposure events, such as those experienced by atomic bomb survivors. Emerging evidence suggests that particle radiation is more harmful than electromagnetic radiation (Montesinos et al., 2021). While predicting the effects of long-term exposure to GCR and SPE is complex and necessitates further research, ethical and financial constraints rightfully impede swift progress in this area.

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