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Preparing for Human Missions to Mars: The role of ISS and Artemis as Analogs for Research and Technology Testing

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Abstract

The hazards of spaceflight to the human system are present in in varying degrees on different spaceflight platforms: altered gravity, isolation and confinement, distance from Earth, radiation, and hostile closed environments. A strategic view of the fidelity of hazards experienced on different platforms can shape the testing plans for human research and technology demonstration related to crew health and performance.

Working across the international partnership, the International Space Station (ISS) is planning periods of modified operations to improve the fidelity of Mars simulations. To understand transit durations as an independent variable, a series of 1-year, 6-month and 30-45 day missions are being planned on ISS. Standard measurements across ISS missions of different durations, lunar missions and ground analogs offers the opportunity to distinguish different hazards and their effects in the context of the relevance to future mission concepts. The ISS partnership is planning for additional test cases that are aligned with Mars mission plans. (1) Evaluating crew performance capabilities when transitioning to gravity after long durations in microgravity representative of a Mars transit. (2) Simulating crew medical care under Mars-like autonomous operations. (3) Identification and testing of operations under communications delay and autonomy expected for Mars missions and the linked effects on behavioral health and performance of the crew.

Artemis missions serve as a valuable analogs for Mars surface operations, with partial gravity and deep space radiation hazards, but with crewmembers that are probably more physically capable than their counterparts would be after a Mars transit. Getting unobtrusive data from early Artemis missions, and knowledge gained from operational experience as Artemis operations develop can improve engineering design, medical requirements and countermeasures, and ultimately ensure mission success on Mars.

Linking Mars architectures with the plans and capabilities for ISS and Artemis allows us to plan to most operationally relevant tests of crew health and performance on current spaceflight missions to inform planning for future missions to Mars. By using human spaceflight platforms as well as ground simulation in an integrated way, the international community can improve exploration readiness, develop countermeasures and reduce risks of future human space missions.

Keywords: International Space Station, Artemis, human spaceflight, astronaut health, risk assessment, analog missions

1. Introduction

From the beginning of human spaceflight, scientists and engineers have sought appropriate analogs to extreme missions where human performance can be tested in order to improve engineering design, medical requirements and countermeasures, and ultimately ensure missions safety and success [1]. For example, the Extended Duration Orbiter Medical Program [2] and NASA-*Mir* Missions [3] were both designed to gain the medical information necessary to reduce the risks of human spaceflight both on the International Space Station (ISS) and subsequent exploration missions beyond Earth orbit. From its inception, ISS has served as a key place for doing research on the effects of microgravity on human physiology and developing mitigations and countermeasures to those effects to enable future exploration [4, 5]. Over the past 20 years of ISS research, significant progress has been made in understanding and counteracting many human health risks considered significant at its inception, such as bone loss [6]. At the same time, new risks and concerns have emerged, such as spaceflight-acquire neuro-ocular syndrome [7].

As the discipline of space medicine has developed a recognition that risks to the human results from varying aspects of the space environment have been clustered into five major hazards of human spaceflight. These hazards are altered gravity, radiation, isolation and confinement, distance from Earth and hostile, closed environments [8].

2. Comparing hazards of human spaceflight in ISS, Artemis, and Mars missions

By considering space missions in terms of the overall hazards of human spaceflight it is possible to identify the areas where these missions are similar to the hazards of a Mars mission and where they differ. Considering each human spaceflight mission as an analog (a thing seen as comparable to another), links both simulated and actual missions on a continuum of development, and provides a structure for considering the design of future missions to ensure advancement of knowledge to eventual human missions to Mars. This strategy connecting ISS, lunar missions, and Mars missions is now being employed in defining mission planning for both upcoming ISS missions as well as Artemis missions to the moon (Table 1).

Table 1. Comparison of ISS and Artemis lunar missions as models of hazards to the human system on future missions to Mars.

Altered Gravity Fields
• Physiological shifts due to microgravity environment over significant durations are the best models for a microgravity transit to Mars (ISS). • Adaptation and performance in partial gravity environments on the moon is the closest analog to partial gravity activities on Mars (Artemis). • There is significant duration-dependence for human adaptation, where short missions may not be comparable to the durations expected of Mars missions. • The combination of time in microgravity plus time on the lunar surface offers an integrated mission model that may reveal aspects of risks to human health that would not be seen separately.
Radiation
• On ISS, the lunar surface, and Mars missions, we assume there will be storm shelters to shield from solar particle events [9]. • ISS radiation exposure is made up of about 50% protons and 50% galactic cosmic rays (GCR), while deep space transit would be dominated by GCR (assuming shielding for solar particle events) [10]. • There is significant duration dependence in radiation response, so early short Artemis missions may not provide as much insight into deep space radiation risks, even if the radiation experienced is more similar to a Mars mission [11, 12].
Isolation and Confinement
• Mars missions will have features that differ significantly from current ISS missions including: limited communication with families and ground support, no visiting vehicles, no care packages or fresh supplies, and no window views of Earth [13]. • The habitable volume on ISS today at about $65m^3$/person [8] is much larger than the exploration standard of $25m^3$/person [14]. • Early lunar missions are likely to have highly limited and confined infrastructure on the surface that is more similar to that expected for early Mars surface missions.
Hostile Closed Environment
• The ISS atmosphere at 14.7 psia and 21% O_2 is similar to Earth at sea level, but 8.2 psi and 34% O_2 is ideal for frequent spacewalks. A range of atmospheres for lunar orbit and surface habitats could also be considered, and may be more or less comparable to Mars mission assumptions [15]. • CO_2 levels have varied significantly on ISS as life support hardware has been improved, and new standards of less than 2 mm Hg are expected to be demonstrated on ISS and Artemis missions [16, 17]. • Microbes of the built environment in ISS air, surfaces and water, have existed with continuous occupancy and multiple inputs over 20 years. In contrast, lunar and Mars systems are expected to have intermittent occupancy, dormant water systems and limited inputs [18]. • The exploration food system may include less variety, but also bulk ingredients and crop production [19]. • Both lunar and Mars missions will need to mitigate dust following surface activities, but the dusts have significantly different properties [20].
Distance from Earth
• Mars is unique from other human spaceflight destinations in having a communications delay of 4-24 minutes, and blackouts of up to 2 weeks. • Communications delay can be simulated on other platforms and ground analogs [21] • Both ISS and Artemis can be used for testing and evolving autonomous systems and autonomous decision support for crews [22]. • Evacuation times from ISS are about a day, from the moon they will be 6-14 days, and there is not an option for evacuation from most stages of a Mars mission.

3. Use cases

Cases for using ISS as an exploration analog were described by Robinson et al. [8]. They include additional 12- month missions to approximate durations of Mars transit, tests of tools for autonomous medical care without ground support, studies of operations and performance on landing day after spending time on ISS [23].

Cases for using Artemis as an exploration analog include both specific studies of human health and performance in partial gravity, as well as integrated missions that combine extended microgravity stays as well as time on the lunar surface (Table 2). Early Artemis missions are critical to study because the lack infrastructure in early missions is likely to be highly representative of the first Mars mission.

Over time as infrastructure and durations both increase, it becomes possible to do combination missions that are analogs for both microgravity transit as well as planetary surface operations. The durations mentioned in Table 1, combined with the expected Mars mission durations are combined to balance numbers of crew subjects and fill knowledge gaps as lunar mission durations increase.

3. International Cooperation

International participation on studies using ISS and future lunar missions as exploration analogs, are important because they help prepare the international cadre of space faring nations for crew assignments and cooperation on future missions.

Knowledge gained from using current missions as Mars analogs can influence approaches to crew selection and assignment, better understanding of the interaction of multinational crews, testing of communications and autonomy with multi-language crews, and building international operations expertise.

4. Conclusions

In essence, every human spaceflight mission is an analog for Mars and each also has limitations. ISS represents the best opportunity for reasonable subjects at long mission durations as an anlaog for microgravity transit to Mars and the effects of microgravity adaptation on return to gravity. It is limited by high levels of activity and its large volume. It may be possible that future commercial platforms in low Earth orbit cold also serve as an analog with appropriate volume for isolation, confinement, and closed environments.

Early lunar missions, and monitoring crew from the first Artemis landing will provide important information relevant to early Mars missions. Lunar surface missions are the most realistic analog we will be able to use for partial gravity, science operations, and dust mitigation. Thinking of every Artemis mission as an analog will help us to advance operational knowledge, technology readiness, as well as better understand the risks to the human in future Mars missions. Testing as many aspects as possible while close to Earth and able to evacuate if needed will held advance our readiness for the first human mission to Mars.

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Table 2. Example integrated lunar mission durations combining microgravity adaptation in orbit with surface activities, with preferred durations and minimum numbers of subjects.

Minimum Duration for Testbed Missions		
Segment	**Duration**	**Rationale:**
Time in Microgravity Pre-Lunar Surface	45-105 days, 75 days preferred.	45 days is the minimum time for the human to adapt to the environment. Previous spaceflight data indicates that in 75 days Spaceflight-associated Neuro-ocular Syndrome (SANS) will manifest in 80% of susceptible people.
Time on Lunar Surface	30-60 days	30 days minimum corresponds to the minimum duration for expected Mars surface ops. Due to the small differential between lunar gravity (1/6g) and microgravity, 60 days might be needed to detect a signal.
Crew Sample Size (N)	N = 4-10 subjects	Allows for meaningful outcomes of data. Four crew is the absolute minimum to see common effects. Ten crew is the minimum sample size for good statistics. Proceeding to longer analog missions preferred over getting more subjects at this durations.
Ideal Extended Lunar Testbed Missions		
Time in Microgravity Pre-Lunar Surface	120-180 days	120-180 day durations in *cis*-lunar orbit prior to lunar surface visits allows for comparison to ISS as a transit analog data. 120 days is the minimum to understand subsequent partial gravity exposure. Space radiation exposure becomes more of a relevant stressor for 120-180 day durations.
Time on Lunar Surface	30-60 days	30 days minimum corresponds to the minimum duration for Mars DRM surface ops. Due to the small differential between lunar gravity (1/6g) and microgravity, 60 days might be needed to detect a signal.
Crew Sample Size (N)	N = 10-12 subjects	Allows meaningful outcomes of data. Ten crew is the minimum sample size for good statistics.
Ultimate Mission Validation		
Time in Microgravity Pre-Lunar Surface	360 days	360 days corresponds to the Mars transit duration, and data collected will be comparable to that from one-year ISS missions.
Time on Lunar Surface	30-60 days	30 days minimum corresponds to the minimum duration for expected Mars surface ops. Due to the small differential between lunar gravity (1/6g) and microgravity, 60 days might be needed to detect a signal. Preceding Extended Lunar Testbed missions and final Mars mission design will inform this duration.
Time in Microgravity post-lunar surface	270 days	270 days corresponds to the expected Mars DRM return duration. Additionally, the overall Ultimate Mission Validation DRM mission duration would be longer than any previous spaceflight mission. Surveilling for long-term health consequence prevention would be required, and the crew would have the opportunity to evacuate if needed.
Crew Sample Size (N)	N = 4-10 subjects	As a validation, this mission may only occur once. Four crew is the absolute minimum to see common effects and allows meaningful outcomes of data, if we are able to leverage data from all other missions and observations. 10 is the minimum sample size for good statistics.