Human Health on the Moon and Beyond and the Results of the Spaceflight for Everybody Symposium

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INTRODUCTION: In 2022, the National Aeronautics and Space Administration (NASA) began launching missions to establish a sustainable human presence on the Moon. One key to success will be maintaining human health. In preparation for longer missions with more diverse crews, the Spaceflight for Everybody Symposium was held to review currently known human spaceflight biomedical knowledge, the future of exploration space medicine, and the ability of NASA to manage the spaceflight human health risks and enable exploration. The symposium highlighted the future of precision health/personalized medicine, the possible spaceflight health acute and lifetime illnesses, and the challenge of identifying appropriate prevention, treatment, rehabilitation, and autonomous medical systems for long-duration spaceflight. The symposium was organized to look back at NASA exploration, science, and leadership successes, celebrate NASA women's leadership, and focus on future Artemis activities, including research and development that will benefit both spaceflight and terrestrial life. NASA current preparations for returning to the Moon have led to increased acknowledgment of the importance of workforce diversity, i.e., to use the best candidate in every work position, including the plan for the first woman and person of color to land on the Moon. NASA is developing plans to use commercial spaceflight research opportunities when the International Space Station is no longer available. Astronaut health decisions will consist of individualized health risk determinations and mitigation strategies and increased medical self-care. Research findings include improved exploration cardiovascular, musculoskeletal, and radiation risk reduction and improved interpersonal support for both astronaut crews and mission control personnel.

KEYWORDS: inclusion, precision, risk, radiation, thrombosis.

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NASA will soon launch missions to establish a sustainable human presence on the Moon. These missions will usher in the discovery of new science knowledge, open possible commercial activity, and teach us how to prepare for exploration missions to Mars. One key for success will be knowing how to maintain human health on these missions.[2,9] Potential health problems abound and NASA has characterized these risks into the following primary hazard headings: 1) the effects of deep space radiation; 2) the possible psychological effects of humans feeling isolated and living in a confined spacecraft or habitat for months to years; 3) the logistic considerations because the space crews will be so far from Earth; 4) the physical and physiological effects of different gravity levels on the human body; and 5) living in a hostile, cold, and dangerous set of environments, both in space and on the Moon or Mars.[31]

In preparation for longer missions with more diverse crews, a Spaceflight for Everybody Symposium was held virtually over a 3-d period in November 2021. The intent of the Symposium was to review current human spaceflight biomedical knowledge, the future of exploration space medicine,[32] and the ability of NASA to manage the spaceflight human health risks and enable exploration. Speakers, including the NASA Deputy Administrator, the NASA Chief Health and Medical Officer, senior biomedical scientists and engineers, current and former astronauts, and others, discussed a broad range of topics. In addition to reviewing the results of NASA's biomedical

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operations and research programs accumulated monitoring and risk reduction research data, the symposium highlighted the future of precision health/personalized medicine, the possible spaceflight health acute and lifetime illnesses, and the challenge of identifying appropriate prevention, treatment, rehabilitation, and autonomous medical systems for long duration spaceflight. Additionally, other health and medical topics were discussed, including the future goal for spaceflight participation for other nontraditional able-bodied people (i.e., those individuals who have a physical condition that otherwise may have been perceived as limiting their ability to participate in space activities).

It is NASA's goal to expand human space exploration and to enable the commercial spaceflight industry. NASA is doing this by helping to expand spaceflight access to all humans through Agency leadership, advances in science, medicine, and engineering, and through commercial and international partnerships.[33] This paper seeks to share the essence of the many presentations delivered and recorded with as broad an audience as possible.

The Spaceflight for Everybody Symposium was organized to span 3 d, with a different yet complimentary theme for each day. The first day looked back at successes in exploration, science, and leadership, and forward to plans for greater inclusivity and diversity in space travel. Day two celebrated the increasing role of women in NASA leadership and management as well as how plans for future exploration are changing to include a broader definition of "astronaut." The third day focused on future activities, including discussions regarding partnering with commercial space travel in both research and exploration, precision medicine, and health innovations that benefit both spaceflight and terrestrial life. The following is a review of most points raised during the Symposium and includes a link to the recorded sessions.

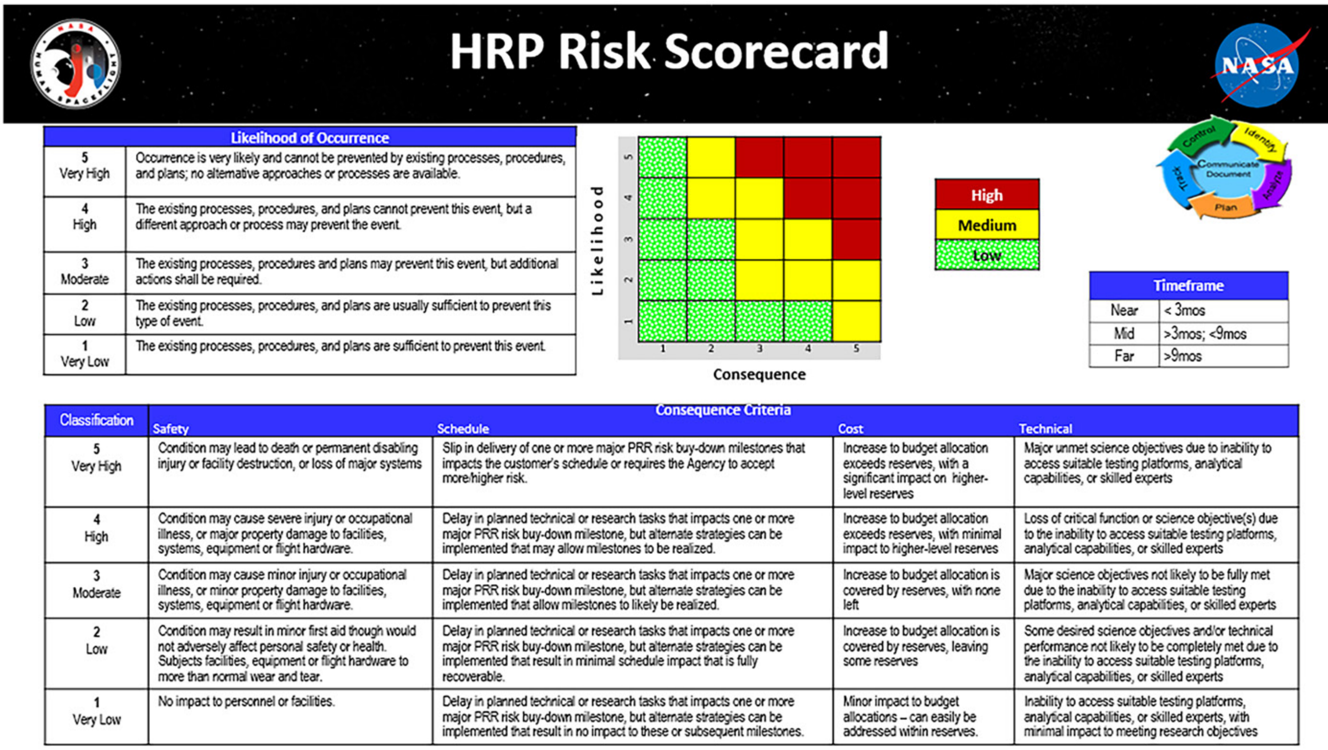
Risk Assessment

NASA has identified the health risks and countermeasures to maintain astronauts' health during spaceflight in low Earth orbit (LEO) with space stays of 6–7 mo or less. Few flyers have been in microgravity for longer than these periods of time and those who have crewed longer missions have not had adequate characterization of possible changes in their anatomy or physiology. It is expected that longer duration missions, with relative isolation and confinement, could also enhance psychology disharmony. This, too, has not been well characterized. Additionally, there is a need to access individual spaceflight risk assessment based not only on sex, age, radiation exposure, and so on, but their specific genetic makeup as well.

Health risk is determined by the Office of the Chief Health and Medical Officer (OCHMO), which sets astronaut career and spaceflight health standards and agency biomedical requirements.[14,48] Currently the NASA OCHMO Health and Medical Technical Authority's Human Systems Risk Board (HSRB) and the Space Operations Mission Directorate's Human Research Program (HRP) assign human health risk to multiple spaceflight biomedical conditions based on mission length, space radiation exposure, and distance from Earth. These risks are summarized for LEO, Moon, and Mars missions.[30,55] In general, using a "traffic light" grading scale, the risks for LEO show only acceptable green or yellow risks. Lunar orbit and surface stays show mostly acceptable green or yellow risks with up to about 15% being red risks. For a Mars orbit or surface stays, about half the risks are in the yellow or red grouping (**Fig. 1**).[30,55]

Examples of the HRP research and Crew Health and Safety operational medical successes for risks reduction for LEO (i.e., risks assigned "green or yellow" based on biomedical research) include:

1. Prevention of radiation carcinogenesis: As a result of NASA's research, we have identified that there does not appear to be an increased risk of cancer death in astronauts due to either LEO or Apollo space radiation levels or other factors in their careers for current and former NASA astronauts, excluding melanoma, which is similarly seen in airplane pilots.[36,46]
2. Adequate health facilities for diagnostics and treatment were established on the International Space Station (ISS). As a result, no one has had to return to Earth due to a medical condition, including treatments of eye problems,[21] deep vein thrombosis,[1,26] dermatitis,[4,11] headaches,[6] irregular heart rhythms,[38,48] and urinary retention.[7]
3. Providing adequate food and nutrition: Crews in Shuttle and early ISS missions almost always lost weight because they ate only 60–80% of their energy requirements. Currently, improved crew education and monitoring has resulted in spaceflight crews maintaining a healthy body weight.[52]
4. Prevention of renal stones and bone fractures: The skeleton atrophies in microgravity because there are no gravitational forces acting on the musculoskeletal system. The atrophy causes bone calcium release and increases the risk for renal stones.[49,52] NASA ground and microgravity research has demonstrated that bone loss can be prevented, and steps can be taken to protect against renal stones and possible bone fractures.[40,49,52] Although on Earth osteoporosis occurs more frequently in women than men, both men and women lose bone at the same rate in microgravity.[50,51]
5. Preventing/monitoring/treating cardiac rhythm problems: Although it appears that cardiac arrythmias are neither increased nor spaceflight-induced, they have occurred and appropriate spaceflight treatment guidelines are available. Previously, an automated external defibrillator (AED) and devices to aid cardiac pulmonary arrest had been flown.[38,43,48] Currently there is one AED on station plus a spare battery. It is expected to last for 10 yr.
6. Treating landing orthostatic intolerance (OI): OI increased from 25% in Shuttle crew to 80% in ISS crew, which is thought to be due to the longer ISS missions. Although this occurs in both sexes, the mechanism causing OI is different in men and women.[43] Since the current suite of



Likelihood of Occurrence	
5 Very High	Occurrence is very likely and cannot be prevented by existing processes, procedures, and plans; no alternative approaches or processes are available.
4 High	The existing processes, procedures, and plans cannot prevent this event, but a different approach or process may prevent the event.
3 Moderate	The existing processes, procedures and plans may prevent this event, but additional actions shall be required.
2 Low	The existing processes, procedures, and plans are usually sufficient to prevent this type of event.
1 Very Low	The existing processes, procedures, and plans are sufficient to prevent this event.

Timeframe	
Near	< 3mos
Mid	>3mos; <9mos
Far	>9mos

Classification	Consequence Criteria: Safety	Schedule	Cost	Technical
5 Very High	Condition may lead to death or permanent disabling injury or facility destruction, or loss of major systems	Slip in delivery of one or more major PRR risk buy-down milestones that impacts the customer's schedule or requires the Agency to accept more/higher risk.	Increase to budget allocation exceeds reserves, with a significant impact on higher-level reserves	Major unmet science objectives due to inability to access suitable testing platforms, analytical capabilities, or skilled experts
4 High	Condition may cause severe injury or occupational illness, or major property damage to facilities, systems, equipment or flight hardware.	Delay in planned technical or research tasks that impacts one or more major PRR risk buy-down milestone, but alternate strategies can be implemented that may allow milestones to be realized.	Increase to budget allocation exceeds reserves, with minimal impact to higher-level reserves	Loss of critical function or science objective(s) due to the inability to access suitable testing platforms, analytical capabilities, or skilled experts
3 Moderate	Condition may cause minor injury or occupational illness, or minor property damage to facilities, systems, equipment or flight hardware.	Delay in planned technical or research tasks that impacts one or more major PRR risk buy-down milestone, but alternate strategies can be implemented that allow milestones to likely be realized.	Increase to budget allocation is covered by reserves, with none left	Major science objectives not likely to be fully met due to the inability to access suitable testing platforms, analytical capabilities, or skilled experts
2 Low	Condition may result in minor first aid though would not adversely affect personal safety or health. Subjects facilities, equipment or flight hardware to more than normal wear and tear.	Delay in planned technical or research tasks that impacts one or more major PRR risk buy-down milestone, but alternate strategies can be implemented that result in minimal schedule impact that is fully recoverable.	Increase to budget allocation is covered by reserves, leaving some reserves	Some desired science objectives and/or technical performance not likely to be completely met due to the inability to access suitable testing platforms, analytical capabilities, or skilled experts
1 Very Low	No impact to personnel or facilities.	Delay in planned technical or research tasks that impacts one or more major PRR risk buy-down milestone, but alternate strategies can be implemented that result in no impact to these or subsequent milestones.	Minor impact to budget allocations – can easily be addressed within reserves.	Inability to access suitable testing platforms, analytical capabilities, or skilled experts, with minimal impact to meeting research objectives

Fig. 1. Human Research Program Risk Scorecard example. This demonstrates how NASA categorizes human system risks by likelihood and consequence.

countermeasures to protect against OI did not protect long-duration astronauts after landing, therapy now includes postlanding intravenous fluids in almost every ISS returning crewmember.[15]

7. Limiting/treating sensorimotor problems in flight and on return to Earth: Space motion sickness during the first 1–3 d of spaceflight was very common during the Shuttle program and, on many occasions, early crew assignments had to be passed off to other astronauts.[41,57] Of equal or greater concern is the impact on the sensorimotor system when returning to Earth or other planetary surfaces as the body transitions from zero G.
8. Maintaining muscle strength and aerobic capacity: Muscles do not work as hard due to the lack of gravity and both voluntary and cardiac muscle atrophy. The use of the Advanced Resistive Exercise Device, in which adequate forces could be generated, as well as appropriated bungy cords to secure an exercising astronaut to the bike or treadmill (mimicking gravity's pull on Earth), comes close to maintaining both muscle strength and aerobic capacity.[49,50] The suite of exercise devices now available on ISS will not be present on long-duration missions to Mars. However, NASA is working to identify and develop other devices to mitigate health impacts during prolonged stays in microgravity to the greatest extent possible.
9. Preventing decompression sickness: ISS is kept at Earth sea-level atmospheric pressure at 14.7 psi. Extravehicular activity (EVA) spacesuit pressures are at 4.3 psi. Decompression sickness is prevented by lowering the potential of nitrogen bubbling at the lower EVA suit pressure. Decompression sickness is mitigated by mask as well as an in-suit "pre-breathe with 100% oxygen and exercise" prior to going to the 4.3 psi pressure. No ISS spaceflight decompression has been seen.[34]
10. Preventing and treating, as needed, sleep loss and fatigue: Both overwork and forced changes of the day-night cycle for launch/landings and other mission required work cause misalignment of the crew's circadian rhythms. This causes sleep loss or poor sleep that may be manifested by early physical or mental fatigue and performance errors. Programs have been developed to inform crews of their best new times for sleep and treatment with light and drug therapy to stabilize circadian rhythms.[18]

Examples of high risk, "red," high-priority research still needed for Mars include:

1. Prevention/diagnosis/treatment/rehabilitation for in-flight medical conditions.
2. Enhanced shelf life for food and medications.
3. Increased behavioral health risk due to relative isolation/confinement/distance from Earth.
4. Injury during work outside a Mars habitat leading to skeletal fractures (e.g., fall or crush injury) or heart problems (e.g., orthostatic intolerance, change in heart structure due to heart remodeling, or increased risk of cardiac arrhythmia).
5. Carbon dioxide or other toxin buildup.

Importantly for both the HSRB and HRP, a "red" risk does not mean that the mission could not proceed, but the likelihood or consequences for this risk of occurrence is at a relatively high level and planning for mitigation of the risk will be a high-priority goal.

Risk is also determined by the unexpected injuries or illnesses that could occur in the very healthy early middle-aged adult astronaut corps. Astronaut medical care is provided by operational medicine flight surgeons [Crew Health and Safety (CHS)], who make sure that astronauts remain "fit for duty," (i.e., certified for spaceflight). A relatively unappreciated fact is that many astronauts remain medically eligible for spaceflight because of healthcare treatment and rehabilitation. During NASA crewed spaceflight opportunities there have been 51 different medical diagnoses, encompassing 90 illness episodes that were remediated, which otherwise could have been career-affecting.[17,45]

Spaceflight Physiological Changes

Spaceflight anatomical and physiological changes occur in spaceflight mostly because the crew is working and living in microgravity. The force of gravity (actually, free fall in LEO) on the human body on the ISS is 10^{-4} to 10^{-5} g and this causes the following to occur (in part):

1. Material and fluid properties:
   A. There is no "up or down".
   B. There is loss of convection and buoyancy—warmer or less dense molecules do not rise, and colder or more dense molecules do not sink.
   C. Loss of hydrostatic pressure—there is no distortion of fluid or elastic solid by being pulled "down" by gravity.
   D. Surface tension forces are more prominent—fluid creeps across a surface.
2. Physiological consequences of the changed material and fluid properties:
   A. Loss of inner ear body position knowledge—potential disorientation and motion sickness.
   B. Fluids are no longer "pulled" down into the lower extremities but redistribute evenly throughout the body, causing a puffy face and possible realignment of the brain within the cranium. The heart may "round-up" instead of being elongated. Nonconnected abdominal organs "float" and push on the diaphragm. Pressure sensors in the skin and other tissues dependent on gravity no longer accurately reflect position or sensation (e.g., joint position, bladder fullness).
   C. Gravity induced exercise effort is significantly reduced, so much so that the muscles and skeleton atrophies. Hypercalcemia and renal stones can be caused by the bone atrophy and decreased strength and early fatigue from the muscle atrophy.

Microgravity physiological changes may only be a normal adaptation, such as how lack of gravity causes muscle atrophy similar to a sedentary lifestyle. On return to Earth, muscle size and strength should fully recover. However, long-term microgravity could also cause anatomical or pathological changes that result in ill health during a mission or after return to Earth. Three areas of spaceflight-induced changes will be discussed in greater detail: increased radiation exposure, eye/brain changes, and deep vein thrombosis.

Radiation. In space, there is a higher level of radiation. Earth's atmosphere, magnetic fields, and radiation belts shield humans from significant radiation damage in LEO. Spaceflight radiation is considered low dose-rate exposure compared with acute radiation terrestrial treatment of cancer. Radiation exposure on the ISS[10] is 30 times Earth's daily background radiation, on the Moon[60] it is 78 times Earth's background, and for a Mars mission it is 230 times Earth's background.[59] Radiation exposure for cancer treatment is 9 million to 16 million times Earth's background daily dose.[56]

The main health and safety concern is the occurrence of an acute solar flare radiation exposure causing tissue damage or death and the development of cancer in the future, as well as possible other health problems related to cardiac or cognitive dysfunction. NASA can construct radiation safe havens using appropriate shielding to protect against acute solar flare biological radiation damage.[54] However, there is currently no long-term radiation damage protection from high-speed, high-energy penetrating galactic cosmic rays.

The effects of space radiation are different on men and women because of sex organ radiation susceptibility and increased radiation-induced lung cancer in women.[10] There is also an age risk. Older people have a greater overall risk of cancer, but younger people exposed to potential cancer-causing radiation, who have longer lifespans, may in the future develop cancer.[37] NASA is using the U.S. Million Worker Study[39] to provide an idea of overall risk, as well as epidemiological data, and a study from the National Council on Radiation Protection on sex-specific lung cancer risk.

Recently the OCHMO changed the radiation standard for missions beyond LEO to a mean 3% extra risk of dying from a space radiation-induced cancer that is not based specifically on sex or age. The new standard effectively increases the career of NASA astronauts and achieves male/female parity. It does this by establishing a universal standard for female and male astronauts of all ages. The career dose limit has been set at 600 mSv. The NASA level of accepted risk is below that allowed by the European Space Agency and the Russian Space Agency. The Japanese Space Agency uses a modified 600-mSv limit that does consider sex and age. This new standard will increase the allowed radiation dose to a 35-yr-old woman by a factor of ~3 and to a 55-yr-old man by a factor of ~1.5.[37] Review of NASA radiation exposure data has not shown increased cancer deaths compared to Earth control data.[46] The updated standard prior to its implementation was reviewed by the National Academy of Sciences[36] and the NASA Bioethics Panel (Weyland M. Personal communication on the NASA OCHMO Bioethical Panel Report on Radiation Health Issues; 2021).

Spaceflight crews are considered radiation workers. Radiation workers on Earth could have appropriate radiation protection with shielding. However, this is not possible for spaceflight crews because of the mass, power, and cost limitations of shielding for both solar and galactic cosmic radiation.[10,36] Understanding all aspects of radiation exposure across a variety of space platforms will be critical to the development of effective prevention and treatment countermeasures in the future. Regardless, NASA accepts the "as low as reasonably achievable" level for radiation safety for astronauts. Based on mission length and when the mission occurs, the radiation risk may be significantly higher.

Eye and brain changes. Spaceflight associated neuro-ocular syndrome (SANS) is manifested during long-duration ISS spaceflight lasting 3 or more months in >70% of crewmembers. Although it was thought to involve both the eye and the brain, the definition was mainly focused on the eye. As more information has been obtained, the definition now includes findings in the eye, brain, and perhaps is even associated with venous blood flow. Documented eye changes include disc edema, choroidal folds, cotton wool spots, nerve fiber layer thickening, globe flattening with permanent scleral remodeling,[24,25] and hyperopic shift in the eye. In the brain, the gray matter volume decreases around the base of the brain, and regional gray matter volume increases in the sensorimotor cortices. Also noted are ventricular expansion and extracellular fluid shifts, upward position shift of the brain with spaceflight, and intracranium volume increases.[19] Findings indicate that the changes are greater the longer the mission (i.e., 6-mo crew < 12-mo crew). Full and partial recovery are seen at 6 mo postflight. Some of the findings in which there was only partial or no recovery seen are in choroidal folds, flattening of the back of the eye, and brain ventricular volume.[25] Some of these brain changes may occur with aging alone; however, all the brain changes seen during an ISS mission were greater than the changes expected for aging over the same time.[25]

Deep vein thrombosis. Two observations of left internal jugular deep venous thrombosis occurred on the ISS, one of which was found in real time, resulting in concurrent anticoagulation therapy.[1,26] Findings included stagnant and reversed jugular blood flow in 6 out of 11 crewmembers studied.[26]

Possible mechanisms for the development of SANS and a neck deep vein thrombosis are currently not known, but could include chronic partial intracranium/neck outflow obstruction due to loss of hydrostatic forces, which induces a headward fluid shift, or other possible small secondary increases in intracranial pressure. It is also uncertain at the present time the level of risk to long-duration crewmembers for both acute and long-term health this/these condition(s) cause(s).

Behavioral Health

Although there have been no published reports of behavioral health problems in short-duration spaceflight and on the ISS, there are concerns noted from other space station missions.[5,22,53] Potential on orbit spaceflight behavioral health stressors have included crew illnesses, death of a family member, significant spacecraft malfunctions, learning of deaths of other astronauts, and family problems occurring on Earth. Additionally, there are other important work relationships that occur on a space mission, such as the interaction of the crewmembers with one another, the interaction of the crew with ground control, the interaction of the crew with their family and friends on Earth, all of which may add to the relative isolation and confinement of long-duration space crews as well as cultural and sex differences between crewmembers. All these factors may add to the difficulty in adapting to a new environment in which the crew will be living and working for extended times.[35]

The potential for behavioral health problems that could affect the outcome of the mission as well as the health of the crew is a major concern for future long-duration space missions. Although current selection and methods work well for LEO behavioral health outcomes, NASA is concerned that once the crew no longer has the ability to return back to Earth in hours, such as when return to Earth and safety may take weeks or years and there are major communication delays (between Earth and Mars up to 20 min one way) and Earth only appears as a lighted dot in the night sky, additional measures will be needed for crew behavioral health. Further, space crews will be more self-directed and need more leadership and coping skills for long distance exploration missions.[9,35,42] HRP, using the ISS and Earth-based analog facilities, is performing research in the following areas to maximize crew health and mission success: work, outside communications, adjustment, group interaction, recreation/leisure, equipment (monitoring health and for exercise and leisure activities), events, organization/management, sleep, and food.[12,31,35]

Planned and Future Destinations

NASA will return human explorers/scientists to the Moon in the next few years to begin a sustainable presence on the Moon and in lunar orbit. Although the main goal for returning to the Moon is for science and to help with the commercialization of space activities, an important element for NASA is to get ready for Mars exploration. Human health is a major reason for using the lunar environment as a place to learn and monitor biomedical issues and to test new methods in prevention, diagnosis, and treatment of both spaceflight–induced health problems as well as unexpected injuries and other illnesses. The first step is the Artemis Program.

With Artemis missions, NASA will land the first woman and first person of color on the Moon and use innovative technologies to explore more of the lunar surface than ever before. NASA will collaborate with commercial and international partners and establish the first long-term presence on the Moon. Then, what was learned on and around the Moon will be used to take the next giant leap, sending the first astronauts to Mars.[23,28,29]

HRP plans to unobtrusively and noninvasively quantify the role of premission training, medical risk management, in-mission workload and countermeasure application, and mission control support to understand the contributions of these factors to the success of mission objectives. Applied research and in-depth characterization of the individuals, along with rigorous collection of environmental and mission metadata are key to understanding the contribution of personal characteristics, both innate and learned, as well as training and in-mission resources such as the application of countermeasures and the role of ground support on mission outcomes. This will be part of the applied research approach that is part of the continuum of research required across all the Artemis missions, enabling the Moon to Mars benefit of the sustainable lunar campaign.[42]

Lunar and Mars health care. CHS serves as the healthcare provider for astronauts who could be assigned a space mission (active astronauts) and provides a comprehensive Astronaut Occupational Health program for the purpose of collecting and analyzing astronaut occupational health data for both active astronauts and any NASA astronaut who is no longer in flying status. This category includes astronauts who are still working for NASA in management positions as well as astronauts no longer working at NASA.

Exploration Medical Capability is a research and development arm of the HRP that advances medical system design and risk-informed decision making for missions beyond LEO to allow for acceptable medical care in extreme environments. Both CHS and Exploration Medical Capability are concerned about how medical care for lunar and Martian missions will change from the current ISS paradigm. Precision/personalized medicine and autonomous medical care are areas they are both investigating and ones that will be important for long-duration spaceflight. Although lunar stays at first will be a month or less, stays for much longer time are in the planning stage. The different potential problems for lunar and Mars healthcare are:

Lunar medical care:

1. Less volume and mass allocation for equipment and supplies;
2. Decreased replenishment of medical supplies;
3. Increased radiation exposure for supplies that may affect/decrease shelf life of nutrients, medications, and laboratory reagents;
4. Repatriation to Earth for health reasons may take up to 30 d;
5. Just-in-time training and medical skills practice requirements; and
6. Continued Earth-based medical consultation as needed.

Mars medical care:

1. Less volume and mass allocation for equipment and supplies;
2. Probable predeployment of equipment and supplies—concern regarding quantity and shelf life;
3. Increased radiation exposure for supplies that may affect/decrease shelf life of nutrients, medications, and laboratory reagents;
4. Repatriation to Earth for health reasons at best would take up to 6–7 mo;
5. Enhanced just-in-time training and medical skills practice requirements; and
6. Communication between Earth and Mars will take from 4–20 min each way based on the distance between the two planets and, depending on the Sun's location, the communication gap may be much longer.
   A. Need for more autonomous medical procedures.
   B. Medical expertise onboard the mission and at the right location. For example, if two crew are in Mars orbit and two crew are on Mars:
      I. the health care provider would need to be where the problem is;
      II. and not be the one with the problem.

Autonomous medicine. A Mars mission requires an autonomous medical system that could perform the right diagnostic and imaging test and then prescribe a therapy that works and is available at the time needed. NASA medical planners need to have knowledge of what medical conditions could/will occur and have this information available aboard the spacecraft. If treatments require just-in-time training or operator proficiency, such learning and training facilities will also need to be available at the right location in the Martian spacecraft or habitat.

Personalized/precision medicine. There are many factors that help determine how a person will react to conditions that cause medical illnesses. This may include their sex and age and their current state of health. Some define personalized medicine as an individual treatment for each person and precision medicine as potential therapy for similar groups of people. In either case, the premise is that by knowing about that person or a similar group, tailored/specific prevention, diagnosis, and treatment plans would be available. Knowledge for these health "plans" would be based on the person's genes and gene biomarkers. Identifying treatment approaches and preventative care based on an individual's genomics could shape the behavioral health, environmental, and lifestyle factors to ensure crew health and performance for space missions.[13]

Biomedical Research Locations

ISS. The ISS will be used in preparation for Mars mission scenarios to measure the time courses of physiological and psychological adaptations to spaceflight to inform crew health and performance risks during multiyear deep space exploration missions.[42] Abundant health and biomedical data exist for staying 6 mo in microgravity on the ISS, but little exists up to and beyond 1 yr. HRP is seeking to extend systematic data collection to determine if, how, and why anatomical and physiological changes continue in crewmembers for spaceflight durations that would mimic a round trip in microgravity to Mars and back.

The study is called Complement of Integrated Protocols for Human Exploration Research (CIPHER). CIPHER consists of 17 total studies: 12 NASA/HRP studies + 5 International Partners studies (CNES, 2 CSA, DLR, JAXA). It is a highly integrated study that looks across the multiple systems in the human body by collecting data, biological samples, and various measurements before, during, and after an astronaut's mission in space.[44]

Analogs. NASA uses terrestrial analogs for specific aspects of space missions. The three types of analogs include:

1. Those that mimic some of the physiological changes that occur in microgravity. For example, the European Space Agency (ESA)/DLR envihab bed rest research unit that is studying the eye and brain changes of spaceflight using a strict head down bed rest model.[16] HRP is now studying potential SANS countermeasures.[20]
2. Confinement and isolation chambers to study behavioral health and psychological stressors, including changes in circadian rhythms, and effects of culture and mixed sex crews; for example, the Human Exploration Research Analog and the Russian Institute for Biomedical Problems isolation chamber studies for learning the best methods for establishing long-lasting teams and leadership to maximize interpersonal relationships.
3. Real work environments located in remote or harsh environments that mimic the Moon or Mars, such as the National Science Foundation Antarctica Station, where science and living logistics are performed in an isolated, cold, and difficult situation for extraction if some behavioral health or medical problem occurs.

NASA

Organizational changes. The Human Exploration and Operations Directorate that oversaw the ISS and the commercial crew program as well as the human spaceflight research and development activities has been split into two organizations: Space Operations Mission Directorate and the Exploration Systems Development Mission Directorate. The Space Operations Mission Directorate will oversee the operational human spaceflight programs including the ISS, commercial crew, cargo mission, and Human Spaceflight Capabilities' CHS, medical operations and the HRP, and biomedical research. The Exploration Systems Development Mission Directorate will oversee the Artemis Moon program and the Moon to Mars program. This will include not only oversight of all the spacecraft systems, but also the responsibility for using the experience gained from the Artemis Program and adapting it for a human mission to Mars. Critical to the success of these two directorates is the effective advancement and integration of commercial spaceflight and international partner participation.

Helping advance the commercial spaceflight sector and increasing NASA's biomedical knowledge. HRP and the Translational Research Institute for Space Health at the Baylor College of Medicine (TRISH) can share lessons learned and guide and give back to the commercial community from NASA's 50+ yr of biomedical experience and TRISH's 6-yr research effort on HRP's behalf. HRP and TRISH can share ground and space health and medical data while they establish healthy and mutually beneficial relationships as a foundation for future collaborations on space missions. HRP wants to engage in commercial science since giving back is part of NASA's governmental mandate of using public funds wisely, and to foster the commercial space industry by sharing health and safety knowledge. HRP can be helped by commercial space efforts when there are research opportunities for HRP to obtain a greater *N* (i.e., a greater number of research subjects to better define space health risks and inform NASA's medical standards). Therefore, commercial platforms will be the future locations for LEO spaceflight biomedical research and collecting health information.

TRISH has been able to take the lead for these research activities by establishing fast and efficient relationships with the commercial industry, and they successfully managed a biomedical research program for the SpaceX Inspiration 4 mission. TRISH has also announced a medical research program to study astronauts' health and performance during commercial spaceflights.

The program, called Enhancing eXploration Platforms and Analog Definition (EXPAND), will collect data from multiple flights and keep it in a centralized database in order to improve the health of astronauts and find new innovations for use at home on Earth. The first mission to collect data for EXPAND was the 3-d long orbital Inspiration 4 mission that was in orbit between September 15 and 18, 2021, in which the Inspiration4 crew participated in 6 biomedical research experiments.

HRP and TRISH have taken the first steps. NASA HRP and TRISH and the commercial spaceflight industry can learn to work together while managing their different priorities. Doing so is the future of space exploration, since there are still a lot of health and medical unknowns.

Working with spaceflight international partners. NASA has had a long history of collaborating with spacefaring international partners.[8] An important and significant area has been in space biology and medicine. Starting early in the space era, NASA Life Sciences has benefited from cooperation with Russia on their Bion free flyers to study model organisms and human physiology during the NASA-Mir Program, on the ISS, and in ground-based analog studies. The ESA, as well as Canada and ESA's individual member states from Germany, France, and Italy, also collaborated with NASA Life Sciences in Shuttle Space Labs, on the ISS, and in ground-based analog studies. NASA and the Japanese Space Agency (JAXA) also have successfully worked together in the Shuttle Spacelab and ISS life science studies.

NASA will continue to value and share spaceflight opportunities with international partners as planning proceeds for the Artemis Program. Together with greater diversity within its own workforce, NASA will continue to improve its mission success.

Improving NASA's mission. NASA's missions are improved by hiring the best employees. This includes everybody who works for NASA regardless of their sex, race, ethnicity, or age. NASA appreciates a diverse workforce. NASA has been voted by its employees as the best place to work in the Federal government for the ninth consecutive year. Over the last 13 yr, led by NASA Administrators Charles Bolden, James Bridenstine, and Bill Nelson, there has been a strong commitment to hire and promote those that can get the job done.[3] This has led to a more inclusive and diverse workforce, where leadership positions are starting to reflect the country's demographics. The symposium highlighted not only the accomplishments of several NASA women and people of color[1,28,58] as leaders, but also their hard work in breaking barriers so their talents could be appreciated.[28,47,58]

The operational and research life sciences organizations that maintain humans in space, the Human Health and Performance Directorate at the Johnson Space Center, and the HRP have made major strides over the last 10–15 yr[27] in that their workforce is now about 44% women and 56% men. HRP's research portfolio statistics show that research proposals awarded by sex is 16% for female investigators and 18% for male investigators from the submitted research proposals. Currently about 40% of the proposals come from female investigators and 60% from male investigators. The life sciences organizations, as well as the rest of NASA, continue to promote highly skilled diversity in the workforce so spaceflight exploration missions can be accomplished.

Discussion

After reviewing the Spaceflight for Everybody Symposium, several major outcomes were noted and are included below:

1. While there are significant human health risks, there are no biomedical "showstoppers" for exploration missions back to the Moon or on to Mars. A certain degree of risk acceptance may be needed, but to minimize this, there is important work/research required to keep this a reality.
2. ISS is the most important research biomedical facility to buy down exploration mission health risk for the future, both for human health and countermeasures and biomedical technology demonstrations in microgravity. However, NASA will depend on cooperation with international partners and the commercial spaceflight sector to continue this research into the future.
3. NASA will monitor astronaut health throughout their NASA careers and beyond to determine if there are any potential health issues associated with spaceflight. NASA's investment in astronaut health allows astronauts to have full space careers by treating or mitigating any health abnormalities and providing valuable data for use in terrestrial medicine.
4. NASA is moving to create precision/personalized medicine (expanding individualized medicine based on their sex and gender and individual characteristics).
5. The NASA biomedical community is in a good position to support the commercialization of space by being able: A) to offer 50 yr of biomedical knowledge; B) offer health care and research consultation as needed to the commercial sector; and C) use the commercial resources to increase the number of spaceflight research subjects now and to continue biomedical research after the ISS is decommissioned for learning the information needed to buy down exploration class mission risk.
6. NASA has and continues to develop approaches (ranging from engineering to medicine) that enable a more diverse group of individuals to participate in spaceflight, program management, engineering, and more, and has embraced this diversity as a force multiplier.
7. Diversity and inclusion encompass more than race, ethnicity, sex, gender, or age, but also extends to thoughts, ideas, and perspectives.

The symposium agenda, list of speakers, and access to the entire program can be found at https://www.nasa.gov/hrp/spaceflightforeverybody.

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