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A moonshot for female astronaut health, a win for all astronauts and space exploration

Check for updates

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Given the increasing involvement of female astronauts in advancing our knowledge of human capacity for long-duration spaceflight, it is critical to determine how to ensure their health and safety, as well as optimize their performance. This commentary discusses the priority to leverage the strengths of innovative collaborations and scientific approaches to enable the identification of potential risks and establish effective countermeasures that will ultimately support the success of space exploration.

There has been a significant increase in women participating in spaceflight over the past decade. More female astronauts than ever have flown on space missions or will fly in the coming years as a part of growing government and commercial space efforts. As a result, more women are exposed to the risks of spaceflight for longer durations than in the past. At the same time, significant gaps in our scientific understanding of women's health have been recognized through recent initiatives that include studying conditions specific to women (e.g., fibroids), conditions that disproportionately impact women (e.g., osteoporosis), and conditions that affect women differently than men (e.g., cardiovascular disease, specific cancers)[1–3]. In turn, major research initiatives are now prioritizing women's health research to fuel the delivery of high-quality and patient-centered healthcare to women. Given the increasing involvement of female astronauts in advancing our knowledge of human capacity for long-duration spaceflight, it is critical to determine how to ensure their health and safety as well as optimize their performance. These data are of value as they also inform how to ensure health and quality of life for those on Earth.

Despite recent advances in research, many questions remain regarding the risks of spaceflight. Those risks include exposure to microgravity, radiation, acceleration, vibration, hypobaric conditions, isolation, and high levels of stress while working within the confines of a spacecraft. Data determining the effects of spaceflight on all human organ systems (including, but not limited to, the genitourinary system) are essential to establishing effective countermeasures to prevent spaceflight-associated morbidity and mortality for all astronauts. These data are also necessary for pre-flight risk mission planning, in-flight risk mitigation, and post-flight recovery and reproductive health maintenance[4–6].

The problem is that, to date, most of the existing information about the risks and outcomes of spaceflight pertains to male astronauts. There is far less data about the impact of spaceflight-associated exposures on female astronauts[7,8], limiting the ability to inform key decisions about human health and performance requisite for successful spaceflight missions. These limitations will become increasingly significant as missions of longer duration and distances from Earth take place. In the coming years, we will see the return of humans to the Moon with the Artemis missions, which will include female astronauts who work in lunar orbit and walk on the Moon. There is also ongoing planning for missions to Mars, which will require data to inform the care of human beings for missions that may last for years, with the increased complexity of significantly delayed (or absent) communication, limited resources, and the inability to rapidly return to Earth for definitive care.

Learning from the past

History gives a compelling reason to investigate the differences between male and female astronauts. Until the late 20th century, animal and human research focused investigations on males without seeking equivalent information among females[9,10]. Fewer women were included in trials; this may be due, in part, to the fact that studies often excluded women of reproductive age. Such restrictions stemmed from fears about the reproductive repercussions of research participation or because certain health issues were erroneously thought to occur predominantly in men (e.g., the risk of myocardial infarction)[3]. Other studies included women but presented insurmountable barriers to their study participation or did not focus on outcomes of interest for them. As a result, essential information was missing or limited regarding the safety and efficacy of numerous drugs and procedures in women. This, in turn, contributed to serious and avoidable medical and ethical harms for women, who experienced higher rates of adverse events and side effects when using an intervention[11,12]. In response, major research institutions moved towards a policy of requiring sex to be examined as a biological variable when designing, conducting, and reporting findings for all human and animal research[13,14]. Thus, sex-based variances in outcomes

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can now be identified and understood, leading to opportunities to personalize healthcare to the needs of all patients.

The present state

There are important reasons to study sex-based differences between male and female astronauts. Studies show that many physiological processes, illnesses, and diseases manifest differently among women and men who live and work on Earth. Examples include cardiovascular, metabolic, and autoimmune diseases, with additional sex-based differences noted in the types and rates of malignancies[15,16]. While predictive modeling using existing terrestrial and spaceflight outcomes data has been created, it remains unknown how such differences will manifest in space with its unique environmental exposures, particularly with long-duration spaceflight.

Despite these differences, there have been a limited number of studies involving female astronauts and comparing outcomes to those of their male counterparts. This is due largely because, historically, fewer women have flown on space missions compared to men, leading to fewer opportunities to collect information about spaceflight risks and effective countermeasures. Further, there have been a limited number of studies focused on either sex-based differences or sex-specific health issues of female astronauts during or after spaceflight.

While gynecologic and reproductive function are specific scientific questions for this population of astronauts, there are many other questions about the impact of spaceflight across all organ systems. For instance, sex-based trends have already been observed among some of the conditions observed in astronauts. Clinical Spaceflight Associated Neuro-ocular Syndrome (SANS) initially appeared more common in male astronauts than female astronauts, though emerging data may suggest otherwise [7,17–21]. Conversely, post-flight orthostatic intolerance and related cardiovascular changes were observed at a higher rate among female astronauts than their male counterparts. However, studies show that there may be other physiological factors unrelated to biological sex driving these changes[22–25]. Why these apparent sex-based differences exist is yet unknown and requires continued momentum for rigorous research determining how biological sex may play a role and developing the appropriate and personalized countermeasures to prevent them.

Specific to reproductive and gynecologic function, fundamental questions exist about the impact of the spaceflight environment on the normal hormonal regulation of the menstrual cycle in humans. There remains a gap in scientific understanding about whether or how the hypothalamic-pituitary-gonadal axis may function during spaceflight, factors that may lead to abnormal uterine bleeding, and other associated conditions that may require medical management during the mission. Animal model data contribute to understanding the impact of spaceflight on function, though they cannot replace human studies. While emerging clinical research is beginning to close the gap[26,27], additional research in humans is needed. There is also a need to identify the effects of microgravity, radiation, and other potential hazards of spaceflight on complex systems that contribute to gynecological health (e.g., the vaginal microbiome) and common gynecological conditions (e.g., fibroids, adenomyosis, and endometriosis). Additionally, there is a paucity of information about ovarian function and the risk of premature ovarian insufficiency (POI), which not only may affect reproductive potential post-flight but also may concomitantly exacerbate the risks of menopause-associated symptoms and conditions (e.g., cardiovascular disease and osteoporosis), with significant implications for in-flight and post-flight health[28]. While research suggest an increased rate of POI among Gulf War Veterans, which is suspected to be due to exposures contributing to ovarian damage, the incidence among female astronauts is unknown[29]. Furthermore, robust investigation is lacking to better understand how the use of countermeasures, such as hormonal modalities, to mitigate the gynecologic pathologies for female astronauts may simultaneously increase or decrease risks of abnormal uterine bleeding, anemia, ovarian cyst formation, osteopenia, and venous thromboembolism[30–32].

Opportunities on the horizon

There are several opportunities to investigate sex-specific and sex-dependent conditions that will increase data about the health, well-being, and performance of female astronauts. These data, in turn, will contribute to developing more nuanced risk identification and countermeasure strategies for all astronauts, with broader applicability to inform the health of women living on Earth. Efforts are underway to identify gaps in data applicable to female astronauts and the research steps needed to characterize female response and sex differences. Terrestrial analogs and predictive risk models provide important insight to inform hypotheses, scientific methodologies, and outcomes for future scientific investigations[33,34]. However, data from astronauts working in human spaceflight's complex systems engineering domain is needed to inform strategies that prevent harm to the individual astronaut, the crew, and the mission. To continue moving the field forward, we advocate for the characterization of sex-specific responses to the stressors of spaceflight, in conjunction with the identification of predisposing factors of individual variability.

The growth of government and commercial spaceflight efforts presents one opportunity to conduct this type of research and apply findings to practical guidance. These efforts present the chance to forge stronger cross-collaboration in developing research agendas that build off the strengths of each sector, identifying data gaps and developing research priorities. Such private-public collaborations would increase the number of women participating in research and would make it possible to conduct more rigorous, high-impact research that employs sex as a biological variable to understand differences across a broader spectrum of diseases and conditions. These collaborations may also pave the way for innovative team science, bringing together different disciplines to leverage emerging computing, conceptual frameworks, predictive models, basic science, and biomedical technologies to accelerate discovery. As the total number of female astronauts increases and more data become available, these collaborations would make it possible to unite methodological approaches consistent with women's health research, which focuses on conditions that are more common, manifest differently, or are understudied in women and would enable analyses comparing findings across subgroups of female astronauts.

There are also opportunities to ensure that the research that takes place addresses the needs of female astronauts so that we may deliver nuanced patient-centered healthcare and individualized countermeasures. Research agendas that identify priorities and approaches to advance science should be developed with past, current, and future female astronauts as key stakeholders. The scientific aspects of the study, including study methodologies and outcomes, should incorporate their interests with the perspectives of aerospace medicine, obstetrician-gynecologists, and women's health clinicians as subject matter experts who can also speak to the risks of spaceflight and the potential impact of anatomical, physiological, and pharmacokinetic differences between males and females for countermeasure preparedness. These conversations should involve researchers across the different disciplines relevant to space exploration to determine how to leverage scientific approaches, such as artificial intelligence, omics, biorepositories, and appropriate analogs, to answer key questions about astronauts' health and performance. Female astronauts should also have a lead role in defining acceptable risks of research and human subject protections, including the protection of potentially sensitive data regarding genetic testing and sexual or reproductive health. Finally, their input is critical to establishing pathways for implementing research findings into practice and informing decisions about their health and participation in spaceflight.

The future of human spaceflight is dependent upon the health, performance, and readiness of all crewmembers. Thus, this is the time to institute a high-impact and robust research agenda to advance scientific understanding of the impact of spaceflight on female astronauts. Such directed efforts would bring together key stakeholders focused on the health of female astronauts to create a consolidated effort toward scientific discovery and implementation of data into effective strategies to support health and performance. Scientific communities have the opportunity to take the lead in developing and operationalizing this agenda. Given female astronauts' role in human exploration, scientists, medical specialists, and policymakers must collaborate with female astronauts to conduct research that answers the most important questions about their health before, during, and after flight. Leveraging the strengths of innovative collaborations and scientific approaches will enable us to identify potential risks and establish effective countermeasures that will ultimately support the success of space exploration.

Data availability

No datasets were generated or analyzed during the current study.

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Competing interests

The authors declare no competing interests.

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