

Pharmacist roles across the space mission pathway

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Abstract

The advancement of human space exploration presents unprecedented healthcare challenges, and heightens the need for specialized pharmaceutical care across the distinct timelines of a space mission. Despite growing interest in integrating pharmacists into space healthcare, their roles remain largely generalized, not tailored to the specific demands of pre-mission preparation, in-mission operations, and post-mission recovery. Each phase introduces unique challenges, including microgravity, radiation, and the constraints of long-duration missions, which can compromise drug stability, alter pharmacokinetics, and impact astronaut health. This commentary addresses these gaps, proposing a timeline-based approach to pharmacist involvement in space missions to ensure tailored healthcare delivery at every stage. These approaches will not only enhance astronaut health and mission outcomes but will also contribute to advancing healthcare practices on Earth. Future efforts should focus on operationalizing these frameworks to optimize pharmacotherapy in space exploration.

Keywords: pharmacist, space mission, timeline of a space mission

Introduction

Space missions are extraordinary undertakings that push the boundaries of human ingenuity and exploration. Since the first forays into space during the mid-20th century, these missions have evolved from brief orbital flights to extended stays aboard the International Space Station (ISS) and ambitious plans for interplanetary travel.¹ Driven by technological advancements, international collaboration, and a relentless pursuit of knowledge, space missions aim to uncover the mysteries of the universe while testing the limits of human endurance.¹ The complex nature of these missions demands comprehensive preparation and seamless coordination across scientific, engineering, and technological disciplines, with healthcare emerging as a cornerstone of mission success.

Space exploration has advanced significantly over the past decades, with human spaceflight missions venturing farther and lasting longer than ever before.² However, these ambitious endeavors introduce unique challenges for ensuring the health and well-being of astronauts.³⁻⁵ As key healthcare professionals, pharmacists possess the expertise to address medication management, drug stability, and health optimization in the extreme conditions of space.⁶ A review paper by Aziz S., et al.,⁶ published in *INNOVATIONS in pharmacy*, highlighted the potential roles of pharmacists in space missions, focusing on their contributions to ensuring medication safety, stability, and efficacy in microgravity environments.

While the paper represented a crucial step toward integrating pharmacists into space healthcare teams, it largely addresses their roles in a general context, leaving gaps in understanding how these roles evolve across different phases of space missions.

Space missions can be divided into distinct timelines,^{7,8} including pre-mission preparation, in-mission operations, and post-mission recovery. Each phase presents unique healthcare challenges, from planning and packing medications on Earth to addressing acute health issues during spaceflight and managing long-term health effects after returning to Earth. These timelines demand tailored pharmacist involvement, as medication requirements and health priorities differ significantly in each phase.⁹ With a comprehensive framework detailing the pharmacist's roles throughout these timelines, support for astronauts is maximized in anticipation of critical moments during their mission.

The lack of specific guidelines for pharmacists in space healthcare exacerbates the challenges of medication management. Studies have shown, for instance, that microgravity and radiation exposure can alter drug stability and pharmacokinetics, potentially compromising their therapeutic efficacy.¹⁰⁻¹³ Additionally, limited resupply opportunities during missions necessitate accurate forecasting of medication needs and the development of strategies to extend drug shelf life. These issues underscore the need for a timeline-based approach to pharmacist involvement, ensuring that astronauts have access to safe and effective pharmaceutical care throughout their missions.

Despite the growing recognition of pharmacists' potential contributions to healthcare, a structured approach to defining their responsibilities across the timeline of a space mission

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remains unexplored. Such an approach is essential for enhancing astronauts' health outcomes, improving mission success rates, and ensuring the sustainability of long-term space exploration initiatives. By analyzing the distinct healthcare needs of each timeline and aligning pharmacist expertise accordingly, we can pave the way for more effective and efficient healthcare delivery in space. This commentary aims to explore and define the roles of pharmacists across the distinct timelines of space missions—pre-mission preparation, in-mission operations, and post-mission recovery.

Roles of pharmacists in the space missions pathway

The timeline framework in Figure 1 categorizes pharmacist's role into three mission phases: pre-mission, in-mission, and post-mission, and Table 1 highlights the challenges across the three critical stages of a space mission. Each phase presents unique challenges and healthcare needs, requiring pharmacists to adopt tailored strategies to ensure astronaut health and mission success.

Pre-mission

The pre-mission phase is a meticulously planned stage spanning several months to years before launch, involving astronaut training, pharmaceutical logistics, and medical preparedness.¹⁴ A critical component of this phase is drug selection, which must account for limited storage capacity, weight restrictions, and the stability of medications in space.^{6,15} Ensuring that all necessary pharmaceuticals remain safe, effective, and appropriately packaged for the extreme conditions of space travel is essential. Environmental stressors such as microgravity, cosmic radiation, and temperature fluctuations can significantly impact drug stability, potency, and pharmacokinetics, necessitating specialized pharmaceutical strategies.^{16,17}

Pharmacists can play a crucial role in the strategic planning and execution of pharmaceutical care during this stage, assisting with drug selection, formulation, and stability testing, and prioritizing medications that retain efficacy under space conditions while adhering to strict payload constraints. Given the limited onboard capacity,¹⁸ pharmacists could collaborate with mission planners to optimize pharmaceutical inventory, ensuring that only essential, multifunctional, and space-stable medications are included in the mission's medical kit. Beyond inventory management, prelaunch pharmaceutical concepts are further integrated into mission planning, astronaut training, and simulation programs. Pharmacists can work closely with expedition teams to refine pharmaceutical logistics, incorporating realistic emergency response scenarios into astronaut medical simulations. These collaborations can also extend to athletic performance and physiological preparedness,¹⁹ with pharmacists helping to design nutritional and pharmacological interventions to mitigate bone demineralization,²⁰ muscle atrophy,²¹ and immune

suppression—all of which are common physiological effects of spaceflight.²²

Table 1. Summary of challenges and pharmacist roles across the space mission pathway

Timeline	Challenges	Pharmacist roles
Pre-mission	Drug stability under space conditions, storage limitations, training needs, regulatory compliance, astronaut-specific medication plans	Conduct stability testing, develop space-stable formulations, design radiation-protected medication kits, train astronauts on pharmaceutical self-sufficiency, collaborate with engineers for innovative packaging, establish mission-specific medication regulations, optimize inventory for limited payload capacity
In-mission	Microgravity-induced pharmacokinetic changes, radiation exposure, limited resupply, altered immune function, psychological stress, acute medical emergencies	Monitor drug integrity using onboard analytical tools, adjust regimens based on astronaut physiological changes, provide real-time telepharmacy support, manage acute and chronic health conditions, implement AI-driven health monitoring for pharmacovigilance, research in-space pharmaceutical synthesis and drug repurposing
Post-mission	Long-term health effects (musculoskeletal deconditioning, cardiovascular changes, immune suppression), medication efficacy review, astronaut rehabilitation, future mission planning	Develop personalized recovery protocols, reassess and adjust medication regimens, analyze mission health data for future pharmacotherapy improvements, contribute to post-mission rehabilitation strategies, publish research on long-term drug stability and astronaut health, refine inventory recommendations for future missions

Pharmacists can collaborate with engineers and biomedical scientists to develop innovative packaging solutions that provide radiation shielding, thermal protection, and optimal storage efficiency. They can also partner with mission healthcare providers to develop personalized medication regimens tailored to astronauts' pre-existing health conditions, anticipated mission demands, and individual metabolic profiles. A key educational component of this phase is astronaut training in pharmaceutical handling, administration, and medical self-sufficiency. Pharmacists can ensure that astronauts are proficient in managing storage conditions, making dose adjustments, and following emergency medication protocols, enabling them to manage their health autonomously in space.

Beyond direct medical contributions, pharmacists can also be involved in developing and advising on drug regulations for space missions, ensuring that medication use aligns with international space agencies' medical policies and mission-specific guidelines. This regulatory oversight ensures compliance, safety, and consistency in pharmaceutical care across space agencies such as NASA, ESA, and private aerospace entities. Pharmacists can contribute to the design, organization, and maintenance of onboard pharmacy systems. The extreme conditions of space necessitate specialized storage solutions, as medications must be protected from temperature fluctuations, radiation exposure, and humidity changes to maintain their stability and potency.⁶

The role of pharmacists in emergency medical preparedness is also vital.²⁹ Given the high-risk environment of space, astronauts may encounter acute medical conditions, including trauma, infections, anaphylaxis, psychological distress, and cardiovascular events.⁶ Pharmacists can collaborate with physicians and mission planners to develop contingency protocols, ensuring the most effective use of limited drug supplies for treating multiple conditions. Furthermore, they could contribute to research on in-space pharmaceutical synthesis, which could allow for the on-demand production of critical medications during extended missions. By integrating pharmaceutical expertise into pre-mission planning, astronaut education, and mission-specific health strategies, pharmacists can help enhance astronaut safety, optimize medication management, and ensure mission success. Pharmacists working in tandem with flight physicians, biomedical engineers, and mission planners can align pharmaceutical care with overall health strategies, contributing to joint simulation exercises, integrated health risk assessments, and decision-making for medication inclusion based on crew-specific health profiles. Pharmacists' expertise in pharmacokinetics complements the diagnostic and preventive roles of physicians, resulting in more robust mission medical planning.

In-mission

The in-mission phase presents a dynamic and evolving set of healthcare challenges, largely due to the physiological adaptations astronauts undergo in microgravity.²³ Prolonged exposure to microgravity leads to fluid shifts, causing headward fluid redistribution that can contribute to intracranial pressure changes and vision impairment.²⁴ Astronauts also experience bone and muscle loss, with studies indicating that bone mineral density in space decreases at a rate of approximately 1–2% per month.^{25–27} These changes can alter drug absorption, distribution, metabolism, and excretion (ADME),²⁸ meaning that medications may behave differently in space than they do on Earth. Furthermore, immune system dysregulation increases astronauts' susceptibility to infections, while radiation exposure may induce DNA damage and oxidative stress, leading to potential long-term health complications.²² Given these risks and the absence of immediate medical intervention from Earth, optimizing pharmaceutical care in space is essential for astronaut safety and mission success.

A major constraint of in-mission pharmaceutical care is the limited ability to resupply medications.¹⁵ Even with meticulous pre-mission planning to ensure an adequate supply of essential medications throughout the journey, unforeseen medical conditions may necessitate dose adjustments or alternative treatments. Pharmacists can play a key role in mitigating these challenges by remotely managing astronaut medications, utilizing telemedicine and AI-driven health monitoring systems. Through real-time biometric data analysis, pharmacists can monitor drug efficacy, adjust dosages, and address adverse effects, ensuring astronauts receive optimal pharmaceutical care despite the physical distance from Earth.

Post-mission

The post-mission phase focuses on addressing the long-term health effects of space travel, including musculoskeletal deconditioning, cardiovascular changes, and immune system suppression.³⁰ Astronauts often face a prolonged recovery period as their bodies readjust to Earth's gravity and normal physiological conditions. Managing these health effects requires a multidisciplinary approach, and pharmacists can play a key role in medication management and rehabilitation planning.

During recovery, pharmacists can work closely with rehabilitation physicians, physiotherapists, and nutritionists to co-develop integrated care plans and evidence-based protocols for managing post-mission health conditions. Their insights into medication effects under microgravity conditions can enhance post-mission treatment protocols, while physicians focus on broader physiological recovery—a synergy that can improve the safety and effectiveness of rehabilitation regimens. And they may review data collected during the

mission to refine medication regimens and address any long-term effects of drug use in space. For example, they may recommend bone-strengthening medications to counteract musculoskeletal deconditioning or immune-supportive therapies to enhance recovery.

Pharmacists can also contribute to research efforts aimed at understanding the long-term effects of space travel on drug stability and efficacy, and can work with space agencies to update medication guidelines and inventory lists based on lessons learned, ensuring that future missions are better equipped to address similar challenges.

Discussion

Pharmacists can play an indispensable role in addressing the multifaceted challenges of space missions, and their integration into space healthcare teams must be informed by the structured frameworks proposed in previous research.³¹ One such framework is the Participation, Action, and Research (PAR) model³¹, which emphasizes an interprofessional, iterative approach that integrates the diverse expertise of pharmacists, physicians, engineers, and mission specialists to solve complex healthcare challenges in space.

The PAR model can serve as a foundation for systematically involving pharmacists in the planning and execution of space missions. By facilitating interprofessional collaboration and enabling pharmacists to actively contribute to decision-making processes, the model ensures that pharmaceutical care is not simply reactive, but also *proactive* in addressing potential health risks during space missions. In the pre-mission phase, for instance, the PAR model could help establish research collaborations focused on understanding the stability of medications under simulated space conditions. Alongside other scientists, pharmacists could participate in designing experiments to test drug formulations against the stressors of microgravity and radiation. Actionable insights derived from such studies would enable pharmacists to recommend optimal storage conditions, packaging materials, and drug formulations for space missions. And the collaborative environment fostered by the PAR model could streamline astronaut training programs, ensuring that crew members are well-versed in medication handling and emergency protocols.

The challenges encountered during the in-mission phase, such as microgravity-induced pharmacokinetic alterations and limited resupply options, underscore the need for dynamic healthcare solutions.^{32,33} The establishment of a Space Pharmacy Council³¹ could provide a centralized body to oversee pharmaceutical care during missions. Such a council would not only set standards for medication management in space but also act as a resource for mission control and astronauts in addressing acute health issues. Pharmacists serving on the council could utilize real-time data from in-mission health monitoring systems to adjust medication

regimens and provide remote consultations, enhancing the adaptability and effectiveness of healthcare delivery in space.

Post-mission recovery presents its own set of challenges, including managing long-term health effects such as musculoskeletal deconditioning and immune system suppression.³⁴⁻³⁶ The PAR model's emphasis on iterative research is particularly relevant in this context, as it allows pharmacists to analyze health data collected during missions and refine rehabilitation protocols accordingly. Furthermore, the Space Pharmacy Council could play a pivotal role in standardizing post-mission pharmaceutical care, ensuring that astronauts receive consistent and evidence-based treatments for their recovery. By bridging the gap between mission-specific insights and broader healthcare practices, the council could also contribute to improving pharmaceutical care for terrestrial populations, particularly those with similar health challenges.

In addition to addressing mission-specific challenges, the integration of pharmacists into space healthcare teams offers broader benefits for advancing space exploration. The iterative processes advocated by the PAR model and the standardization efforts spearheaded by the Space Pharmacy Council could serve as a blueprint for other healthcare professionals involved in space missions. Lessons learned from pharmacist-led initiatives in medication stability and pharmacokinetics could, for example, inform the work of nutritionists, physiologists, and psychologists in optimizing astronaut health. By fostering a culture of collaboration and continuous improvement, these frameworks ensure that space healthcare remains at the forefront of innovation. Future frameworks should define role boundaries and interdependencies among healthcare providers, clarifying the pharmacist's unique contribution to medication safety, pharmacovigilance, and therapy customization. This clarity is essential in environments where every professional must operate at peak capacity under extreme constraints.

While this commentary provides a structured framework for pharmacist roles across space missions, it does not comprehensively address the extended responsibilities of pharmacists in deep-space and interplanetary missions. Long-duration space travel, such as to Mars or beyond, presents additional pharmaceutical challenges, including longer drug shelf-life requirements, potential in-space manufacturing of medications, and the need for advanced autonomous pharmaceutical care. Future research should focus on developing strategies for extended mission pharmacy, including novel drug formulation techniques, resource-limited pharmaceutical management, and long-term astronaut health monitoring.

Additionally, this commentary does not extensively discuss the role of pharmacists in disaster response scenarios during

space missions. Unexpected medical emergencies such as radiation exposure events, toxic gas leaks, or life-threatening illnesses may require emergency pharmaceutical protocols, rapid response medication deployment, and innovative therapeutic solutions tailored to space environments. Future studies should explore how pharmacists can contribute to emergency preparedness, crisis intervention, and medication triage strategies for unforeseen spaceflight medical crises. By addressing these gaps in extended space mission pharmaceutical care and disaster response planning, future research can further establish the critical role of pharmacists in ensuring the safety, sustainability, and resilience of long-duration human space exploration.

Conclusion

Pharmacists are essential members of the interprofessional space healthcare team, contributing unique expertise across all mission phases. From pre-mission planning to in-mission support and post-mission recovery, their roles in medication management, pharmacovigilance, and therapeutic guidance complement those of physicians and other specialists. Establishing frameworks like the Space Pharmacy Council and PAR model will strengthen collaboration and ensure safe, effective pharmaceutical care in space. These innovations can also inform healthcare practices on Earth.

List of abbreviations:

NASA National Aeronautics and Space Administration

ESA European Space Agency

DNA Deoxyribonucleic Acid

AI Artificial Intelligence

PAR Participation, Action, Research

ADME Absorption, Distribution, Metabolism, and Excretion

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References

1. A brief history of space exploration. 20 January 2025. Accessed 20 January, 2025. <https://aerospace.org/article/brief-history-space-exploration>
2. McCurdy HE. *Space and the American imagination*. JHU Press; 2011.
3. Sharma R. Likely challenges facing future astronauts assigned to long duration space flights. *Neurology India*. 2019;67(Suppl 2):S170-S171.
4. Sandal GM, Leon GR, Palinkas L. Human challenges in polar and space environments. *Life in extreme environments*. 2007:399-414.
5. Doarn CR, Polk J, Shepanek M. Health challenges including behavioral problems in long-duration spaceflight. *Neurology India*. 2019;67(Suppl 2):S190-S195.
6. Aziz S, Raza MA, Noreen M, Iqbal MZ, Raza SM. Astropharmacy: Roles of Pharmacist in Space. *INNOVATIONS in pharmacy*. 2022;13(3)
7. Chien S. A generalized timeline representation, services, and interface for automating space mission operations. *SpaceOps 2012*. 2012:1275459.
8. Chien S, Tran D, Rabideau G, Schaffer S, Mandl D, Frye S. Timeline-based space operations scheduling with external constraints. 2010:34-41.
9. Astronaut training and mission preparation. 15 January, 2025. https://www.nasa.gov/wp-content/uploads/2015/10/160410main_space_training_fact_sheet.pdf.
10. Wotring VE. Chemical potency and degradation products of medications stored over 550 earth days at the international space station. *The AAPS journal*. 2016;18:210-216.
11. Du B, Daniels VR, Vaksman Z, Boyd JL, Crady C, Putcha L. Evaluation of physical and chemical changes in pharmaceuticals flown on space missions. *The AAPS journal*. 2011;13:299-308.
12. Chuong MC, Prasad D, LeDuc B, Du B, Putcha L. Stability of vitamin B complex in multivitamin and multimineral supplement tablets after space flight. *Journal of pharmaceutical and biomedical analysis*. 2011;55(5):1197-1200.
13. Zwart S, Kloeris V, Perchonok M, Braby L, Smith S. Assessment of nutrient stability in foods from the space food system after long-duration spaceflight on the ISS. *Journal of food science*. 2009;74(7):H209-H217.
14. Seedhouse E. *Prepare for launch: the astronaut training process*. Springer Science & Business Media; 2018.
15. Johnston SL, Blue RS, Jennings RT, Tarver WJ, Gray GW. Astronaut medical selection during the shuttle era: 1981-2011. *Aviation, Space, and Environmental Medicine*. 2014;85(8):823-827.
16. Mehta P, Bhayani D. Impact of space environment on stability of medicines: challenges and prospects. *Journal of pharmaceutical and biomedical analysis*. 2017;136:111-119.

17. Kiefer J, Pross H. Space radiation effects and microgravity. *Mutation Research/Fundamental and Molecular Mechanisms of Mutagenesis*. 1999;430(2):299-305.
18. Vassev E, Hinchey M. On the autonomy requirements for space missions. *IEEE*; 2013:1-10.
19. Hooper AD, Cooper JM, Schneider J, Kairuz T. Current and potential roles in sports pharmacy: a systematic review. *Pharmacy*. 2019;7(1):29.
20. Stavnichuk M, Mikolajewicz N, Corlett T, Morris M, Komarova SV. A systematic review and meta-analysis of bone loss in space travelers. *npj Microgravity*. 2020;6(1):13.
21. Lee PH, Chung M, Ren Z, Mair DB, Kim D-H. Factors mediating spaceflight-induced skeletal muscle atrophy. *American Journal of Physiology-Cell Physiology*. 2022;322(3):C567-C580.
22. Crucian BE, Choukèr A, Simpson RJ, et al. Immune system dysregulation during spaceflight: potential countermeasures for deep space exploration missions. *Frontiers in immunology*. 2018;9:1437.
23. Demontis GC, Germani MM, Caiani EG, Barravecchia I, Passino C, Angeloni D. Human pathophysiological adaptations to the space environment. *Frontiers in physiology*. 2017;8:547.
24. Nelson ES, Mulugeta L, Myers JG. Microgravity-induced fluid shift and ophthalmic changes. *Life*. 2014;4(4):621-665.
25. Stein TP. Weight, muscle and bone loss during space flight: another perspective. *European journal of applied physiology*. 2013;113:2171-2181.
26. Lang T, Van Loon JJ, Bloomfield S, et al. Towards human exploration of space: the THESEUS review series on muscle and bone research priorities. *npj Microgravity*. 2017;3(1):8.
27. Thornton W, Bonato F, Thornton W, Bonato F. Loss of Muscle and Bone During Spaceflight. *The Human Body and Weightlessness: Operational Effects, Problems and Countermeasures*. 2017:121-176.
28. Dello Russo C, Bandiera T, Monici M, et al. Physiological adaptations affecting drug pharmacokinetics in space: what do we really know? A critical review of the literature. *British Journal of Pharmacology*. 2022;179(11):2538-2557.
29. Pincock LL, Montello MJ, Tarosky MJ, Pierce WF, Edwards CW. Pharmacist readiness roles for emergency preparedness. *American Journal of Health-System Pharmacy*. 2011;68(7):620-624.
30. Moore ST, Dilda V, Morris TR, Yungher DA, MacDougall HG, Wood SJ. Long-duration spaceflight adversely affects post-landing operator proficiency. *Scientific reports*. 2019;9(1):2677.
31. Raza A. Advancing Astropharmacy: PAR Model and Space Pharmacy Council to Preparing Pharmacists for Space Missions. *INNOVATIONS in pharmacy*. 2024;15(4):1-1.
32. Blue RS, Chancellor JC, Antonsen EL, Bayuse TM, Daniels VR, Wotring VE. Limitations in predicting radiation-induced pharmaceutical instability during long-duration spaceflight. *npj Microgravity*. 2019;5(1):15.
33. Springel M. The Human Body in Space: Distinguishing Fact from Fiction. *Science in the News* Available online: <https://sitn.hms.harvard.edu/flash/2013/space-human-body/> (accessed on 20 July 2013). 2013;
34. Ramachandran V, Dalal S, Scheuring RA, Jones JA. Musculoskeletal injuries in astronauts: review of pre-flight, in-flight, post-flight, and extravehicular activity injuries. *Current Pathobiology Reports*. 2018;6:149-158.
35. Chung M, Lee PH. Challenges of the musculoskeletal system in space. *Precision Medicine for Long and Safe Permanence of Humans in Space*. Elsevier; 2025:335-349.
36. Mortazavi S, Motamedifar M, Namdari G, Taheri M, Mortazavi A. Counterbalancing immunosuppression-induced infections during long-term stay of humans in space. *Journal of Medical Hypotheses and Ideas*. 2013;7(1):8-10.

Figure 1. Pharmacist roles across Space Mission pathway

