JOURNAL OF PHARMA INSIGHTS AND RESEARCH

REVIEW ARTICLE

A Review on Current Innovation in Space Medicine

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Publication history**:** Received on 14th March; Revised on 23rd March; Accepted on 25th March

Article DOI: 10.5281/zenodo.10950949

Abstract: Space exploration presents unique challenges to human health and well-being, which demand specialized medical research and intervention strategies. Space medicine is a field that involves the prevention, diagnosis, and treatment of medical conditions that arise during the space mission. Astronauts are facing so many health issues due to microgravity, space radiation, isolation and confinement, gravity fields, and hostile and closed environments. In space, the stability of drugs is also affected. The present data indicates that physiological changes occurring during space missions might certainly alter drug potency, efficacy, and safety, which rely on the drug, formulation, duration of space travel, and environmental conditions. With no possibility of resupply, researchers are grappling with the shelf life of the existing pharmaceuticals. The current state of medicine in space is all about storage, management, and adopting conventional medicinal manufacturing in space. In recent days, some innovative research has focused on personalized medicine with the aid of biomarkers, fabricating medicine in space, and genetically modified approaches. The future of space medicine will be characterized by innovation, collaboration, advancing human healthy and exploration beyond the earth's atmosphere.

Keywords: Space exploration; Microgravity; Personalized medicine; Drug potency; Drug stability.

1. Introduction

Space research delves into the exploration, understanding, and utilization of the vast cosmos beyond our planet's boundaries. This dynamic field encompasses a broad spectrum of scientific inquiries, technological advancements, and interdisciplinary collaborations aimed at unraveling the mysteries of the universe and unlocking its potential for the benefit of humanity. Space medicine is an integral and continually evolving field, is essential for human exploration beyond Earth's confines. [1-4] This field ensures the survival, function, and performance of individuals in the demanding and potentially hazardous space environment. In past US missions, this field has grown substantially. To demonstrate that human can survive and work in space for longer periods and emphasis to conquer the biomedical challenges related with long duration space missions which include effect of microgravity on human physiology, pathophysiology, pharmacodynamics and treatment. Space research has made significant contributions to medicine by addressing the unique challenges of human health in space. These challenges have spurred the development of technologies and medical practices that are beneficial not only for astronauts but also for patients on Earth. The advancements in diagnostics, treatment, and the understanding of human physiology gained from space research have the potential to revolutionize healthcare, making it more accessible, efficient, and effective. [5]

Research in space medicine tackles medical challenges like motion sickness, imbalances in nitrogen and calcium levels, anemia, and radiation exposure, which have relevance to medical practice outside of aerospace medicine [6]. Present-day strategies for the manufacture, storage, and management of medicines in space are introduced to set the scene, before providing a forward look on emerging technologies that could be adopted to support on-demand manufacturing of medicines and medical devices. These technologies are namely Chemputing, synthetic biology, and 3D printing.

2. Scope of medicine in space

The scope of medicine in space is vast and multifaceted, encompassing various activities and challenges that are crucial for ensuring the well-being and optimal performance of astronauts operating in the unique and hostile environment of space. This specialized field of medicine is rapidly evolving to meet the demands of increasingly ambitious space exploration missions.[7]

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Space medicine encompasses a wide range of disciplines, including physiology, psychology, biomedical engineering, environmental health, and more. [8] Its primary objective is to understand and mitigate the adverse effects of the space environment on human health and performance, such as microgravity, radiation exposure, isolation, confinement, and the psychological stresses associated with long-duration spaceflight. Researchers and practitioners must address physiological concerns like muscle atrophy, bone loss, cardiovascular deconditioning, neurovestibular disturbances, and the risks of developing conditions like space anemia, fluid shifts, and vision impairment. Managing medical emergencies, trauma, potential infectious disease outbreaks in enclosed habitats, and delivering remote medical care are also critical aspects.[9]

As human exploration pushes further into deep space, space medicine faces unprecedented challenges. The Artemis program, aimed at establishing a sustainable presence on the Moon as a stepping stone for eventual crewed missions to Mars, introduces longer mission durations, increased radiation exposure from solar particles and galactic cosmic rays, and the need for greater medical autonomy. Furthermore, the advent of reusable and recyclable rocket technologies, like SpaceX's Starship system, is enabling more frequent and affordable access to space. [10] However, this also means more people will be exposed to the hazards of spaceflight, requiring robust medical screening, monitoring, and contingency response protocols.

To tackle these obstacles, space medicine is leveraging cutting-edge technologies and approaches, such as:

- Advanced biomedical monitoring and telemedicine systems for real-time health tracking and remote diagnoses
- Specialized exercise regimens, dietary interventions, and pharmaceutical countermeasures to combat physiological deconditioning
- Radiation shielding materials, biological countermeasures, and environmental controls to mitigate radiation exposure
- Developments in regenerative medicine, tissue engineering, and bioprinting for in-situ medical manufacturing and treatments
- Psychological support programs, virtual reality environments, and human-robotic interactions to promote mental well-being during isolation [11-14]

3. Health challenges faced by astronauts in space

The unique and extreme environment of space presents a myriad of health challenges for astronauts, both during their missions and in the periods before and after spaceflight. These challenges arise due to the harsh conditions encountered in space, including microgravity, radiation exposure, isolation, and confinement. The field of bioastronautics, in collaboration with various disciplines such as physiology, psychology, and nutrition, aims to comprehensively understand and mitigate these health risks to ensure the safety, well-being, and optimal performance of space travelers. [15] Fluid distribution in microgravity is illustrated in Figure 1.

3.1. Pre-Flight Challenges

Before embarking on space missions, astronauts undergo rigorous medical evaluations and training to prepare their bodies and minds for the demands of spaceflight. [16, 17] However, even during this preparatory phase, they may face challenges such as:

- Psychological stress and anxiety related to the risks and uncertainties of space travel
- Intense physical training regimens to maintain cardiovascular fitness and muscle strength
- Dietary adjustments and nutritional counseling to ensure adequate nutrient intake and hydration

3.2. In-Flight Challenges

During their time in space, astronauts experience a multitude of physiological and psychological challenges due to the microgravity environment, radiation exposure, and isolation from familiar surroundings: [18]

- Musculoskeletal deconditioning, including muscle atrophy and bone loss
- Cardiovascular adaptations, such as fluid shifts and changes in heart function
- Neurovestibular disturbances, leading to space motion sickness and spatial disorientation
- Impaired immune system function and increased susceptibility to infections
- Vision changes and increased intracranial pressure (known as Visual Impairment and Intracranial Pressure syndrome, or VIIP)
- Alterations in brain structure and cognitive function, including difficulties with memory, attention, and decision-making
- Sleep disturbances and circadian rhythm disruptions
- Psychological challenges, such as stress, anxiety, depression, and interpersonal conflicts due to isolation and confinement

3.3. Post-Flight Challenges

Even after returning to Earth, astronauts may continue to experience various health effects, some of which can persist [19] for extended periods:

- Readjustment to Earth's gravity, leading to orthostatic intolerance and balance issues
- Ongoing muscle weakness and bone loss, requiring rehabilitation and exercise interventions
- Cardiovascular deconditioning, necessitating gradual reintroduction to physical activity
- Persistent vision problems and increased intracranial pressure
- Cognitive deficits, including memory and attention problems
- Sleep disturbances and circadian rhythm disruptions
- Emotional and psychological challenges related to reintegration into normal life

3.4. Nutritional Challenges

Maintaining proper nutrition is crucial for astronauts' health and performance, but it presents unique challenges in the space environment:

- Ensuring adequate nutrient intake and absorption, as microgravity can affect digestion and metabolism
- Developing food systems that provide fresh, palatable, and nutritionally complete meals with extended shelf-life
- Mitigating the effects of radiation on food quality, nutrient content, and potential contamination
- Addressing potential changes in taste and smell perception, as well as appetite fluctuations in microgravity [20, 21]

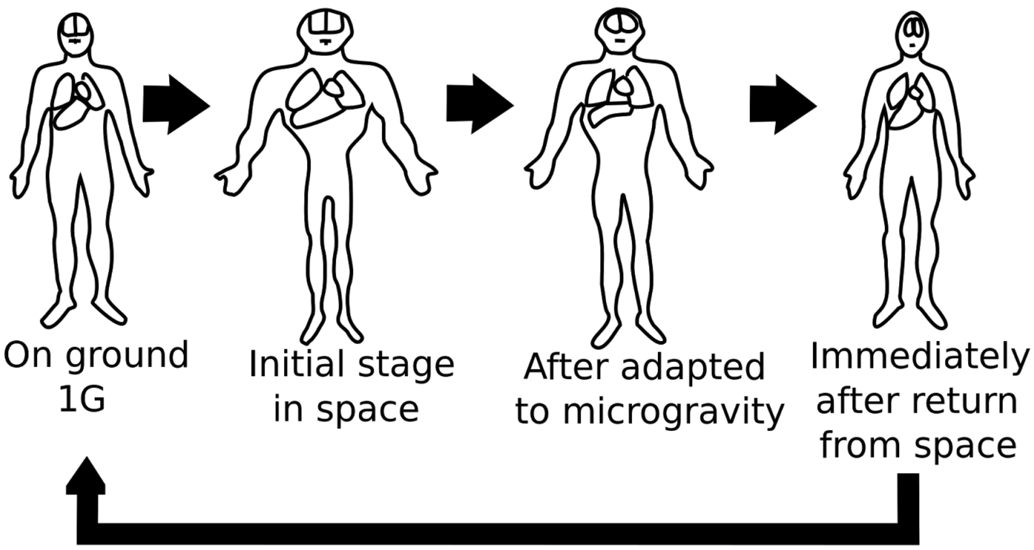

Figure 1. Fluid distribution in microgravity [1]

4. Role of AI in Space Medicine

Artificial Intelligence (AI) has emerged as a transformative force across various domains, and its applications in space medicine hold immense potential for advancing human exploration and habitation in the extraterrestrial environment. The integration of AI into space medicine offers numerous opportunities and addresses unique challenges posed by the harsh conditions of space.[22]

AI applications in space medicine span a wide range of areas, including:

4.1. Autonomous Systems and Robotics

- Self-guided navigation and control of spacecraft and planetary rovers
- Intelligent health monitoring and diagnostic systems for spacecraft and habitats
- Effective oversight and coordination of satellite constellations and communications networks

4.2. Data Analytics and Decision Support

- Analysis of vast datasets from biomedical monitoring, environmental sensors, and mission telemetry to detect patterns and anomalies
- Predictive modeling and risk assessment for astronaut health and mission operations
- Intelligent decision support systems for medical emergencies and contingency planning

4.3. Medical Imaging and Diagnosis:

- Automated analysis and interpretation of medical images (e.g., radiology, pathology, dermatology) for early detection and diagnosis
- Computer-aided detection and classification of abnormalities, lesions, or disease indicators

4.4. Personalized Medicine and Treatment:

- Tailored treatment plans and medication regimens based on individual astronaut profiles and real-time health data
- Optimization of countermeasures and interventions for spaceflight-induced physiological changes [23]

4.5. Robotic Surgery and Telemedicine

- Robotic surgical systems for remote or autonomous medical procedures
- Telepresence and augmented reality technologies for remote medical consultations and guidance

4.6. Crew Assistance and Training

- Intelligent virtual assistants and tutoring systems for medical procedures and crew training
- Simulation environments for realistic scenario-based training and skill development

Moreover, the integration of AI with blockchain technology presents exciting possibilities in areas such as:

- Space Object Connectivity: Secure and decentralized tracking and communication with space assets
- Satellite Communication: Resilient and tamper-proof data transmission networks
- Securing Spacecraft Data: Immutable and distributed storage of critical mission data

In the realm of healthcare on Earth, AI has demonstrated its potential in analyzing complex datasets, detecting patterns, interpreting medical images, and providing personalized care recommendations for chronic diseases. These capabilities can be leveraged and adapted for space medicine applications, such as precise treatment recommendations, minimizing medical errors, and enhancing participation in clinical trials. As space exploration progresses towards establishing long-term human settlements beyond Earth, AI is anticipated to play a crucial role in augmenting or supplementing human capabilities. Intelligent systems capable of human-like reasoning, decision-making, and data analysis will be vital for ensuring the safety, health, and well-being of space-faring crews and future space-born generations. [23]

However, the integration of AI in space medicine also faces unique challenges, including:

- Adapting to changing patient demographics and physiological alterations induced by spaceflight
- Ensuring data integrity, privacy, and security in remote and resource-constrained environments
- Developing robust and fault-tolerant AI systems capable of operating autonomously in harsh space conditions
- Addressing ethical considerations, such as transparency, accountability, and human oversight in critical medical decisions [24]

5. Future of space medicine

The future of space medicine is an exciting and rapidly evolving field that addresses the unique challenges posed by microgravity and cosmic radiation. The International Space Station (ISS) has served as a crucial laboratory for conducting cutting-edge medical experiments, advancing not only space health but also having profound implications for medicine on Earth. With more than 300 medical experiments carried out aboard the ISS, groundbreaking discoveries have been made in areas such as astronaut well-being, medical product development, and pharmaceutical production in space environments. One of the most promising developments in this field is the "Chemputer," a revolutionary device designed to discover and synthesize new drugs on demand. Consisting of four modules – a reactor, filter, separator, and rotary evaporator – the Chemputer allows crewmembers on space missions to download computer code for new molecules and create them on-board. This capability could revolutionize the way medicines are produced and distributed, especially during long-duration space missions where access to traditional pharmaceutical supply chains is limited. [25]

Another fascinating area of research is the concept of "growing your own drugs." Researchers from the University of California, Davis, have made significant strides in designing food and drugs suitable for long-distance space travel. They have successfully genetically engineered lettuce to produce a human hormone called parathyroid hormone (PTH), which is known to promote bone growth. This innovation could potentially address the bone loss and muscle atrophy issues faced by astronauts during extended space missions. Space chip technology is another critical area of development, encompassing a variety of applications and innovations designed for the unique challenges of the space environment. These chips are integral to various aspects of space exploration, including communication, data processing, and the study of physiological changes in microgravity. One example is tissue chips, also known as micro physiological systems (MPS), which are promising toolsets for space biomedicine. These relatively small devices can recapitulate tissue-level physiology and potentially operate in an automated manner, making them ideal for use in space habitats. [27]

6. Stability of medicine in outer space

Ensuring the stability of medications in space is vital for safeguarding the health and well-being of astronauts during space missions. The distinct conditions of space, including microgravity, radiation, and significant temperature variations, can impact the effectiveness and longevity of pharmaceuticals. This is crucial for sustaining astronaut health throughout extended space missions.

Antimicrobial medications might encounter decreased effectiveness in space due to compromised immune responses in astronauts and alterations in pathogens caused by gravity and radiation. To uphold drug stability, it is recommended to explore innovative pharmaceutical formulations and utilize radio protective packaging. [28]

Space medicine is a developing area that deals with the well-being and capabilities of humans in space, concentrating on methods to counteract the physiological impacts of space travel and operational medical concerns, such as maintaining the stability of medications. The space environment presents hurdles to medication stability, with factors like microgravity, vibration, vacuum, humidity, temperature, and radiation possibly diminishing potency. Existing protocols entail replacing medications on the International Space Station before expiration, yet extended missions necessitate medications capable of enduring stability over the long term [29]

7. Conclusion

Space medicine plays a pivotal role in enabling safe and productive human exploration of space. It addresses the physiological and psychological challenges posed by the unique space environment, such as microgravity, radiation, isolation, and confinement. Advancements in space medicine are crucial for maintaining astronaut health and performance during long-duration missions beyond low-Earth orbit. This multidisciplinary field encompasses research areas like human physiology, radiation protection, telemedicine, and development of countermeasures and life support systems. As humanity continues to push the boundaries of space travel, innovations in space medicine will be vital for ensuring the well-being of space farers and future space-born generations, ultimately enabling sustained human presence throughout the cosmos

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Author's short biography

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Dr. Senthil Kumar Chelladurai currently working as Professor & Head in Department of Pharmaceutics at Sri Shanmugha College of Pharmacy, Sankari, Tamilnadu, India. I attained my Ph.D in Pharmaceutical Technology in the year January 2020 from Anna University, Chennai, Tamilnadu. He has completed M. Pharm in the year April 2008, Department of Pharmaceutics from Bharathidasan University, Tiruchirappalli, Tamilnadu and B. Pharm in the year February 2006 from The Tamilnadu Dr. M.G.R Medical University, Chennai, Tamilnadu. He has more than 16 years of experience in the field of Pharmacy profession in academic and research. In 16 years of experience, he was participated around 60 various Conferences, Workshops and Seminars. I also presented around 100 research and review papers at national & international level Conferences, Workshops and Seminars. He had published more than 17 research and review articles in several national and international peer reviewed journals with overall impact factor more than 12. He was published more than 7 Book Chapter as main author and co-authors in Elsevier publisher. He had given invited lecture as resource person in many Conferences and Faculty Development Programmes. Currently he is doing research in the area of nanotechnology in ocular drug delivery system & herbal nanoformulation in various routes of drug delivery systems with academic contributions.

Ajitha Natarajan

Currently pursuing my II-year bachelor's in pharmacy at Sri Shanmugha College of Pharmacy, I am Ajitha Natarajan, quite interested in regenerative medicine and deep knowledge in chemistry. While simultaneously being deeply intrigued prominent role of medicine in microgravity.

Dr Prema R

Dr. Prema R, holding degrees in M. Pharm, Ph. D., and L. L. B., currently serves as a professor at Sri Shanmugha College of Pharmacy in Sankari, Tamil Nadu, India. I awarded Ph.D. in 2014; I boasts 15 years of extensive experience across various universities, with a robust background in pharmaceuticals. Driven by a profound interest in herbal nanotechnology, regenerative medicine, and artificial intelligence, I continuously pioneer innovative research in these fields. Awarded with Young women scientist award at Venus internationals Foundation and Best Teacher award at MNR Educational Trust. Published 15 research papers and presented 80 papers at various national/international conferences and seminars.

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Currently pursuing my II-year bachelor's in pharmacy at Sri Shanmugha College of Pharmacy, I am Selva Bharathi Saravanan, deeply captivated by the realms of cancer research and nanotechnology. While simultaneously being deeply intrigued by the integration of artificial intelligence into the pharmaceutical sector and space medicine.

Sivasakthi Rajendiran

Currently pursuing my II- year bachelor's in pharmacy at Sri Shanmugha College of Pharmacy, I proudly introduce myself as Sivasakthi Rajendiran, a seeker of innovation and a passionate on microbiology

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Dr. Prem Kumar P currently working as Professor & Head in Department of Pharmaceutics at Tagore College of Pharmacy, Rathinamangalam Chennai. Tamilnadu. India. He has more than 16 years of experience in the field of Pharmacy profession in academic and research. In 16 years of experience, he has participated around 50 various Conferences, Workshops and Seminars. He also published around 25 research and 25review papers at national & international level Conferences, Workshops and Seminars. He had Evaluator for poster presentations of Pharmacy Colleges and IPC. He has attended Faculty Development Programme for various Pharmacy Colleges one Book Chapter as co-authors in publisher text book Futuristic Trends in Chemical material in Science & Nanotechnology. Title Converging Nanosensors and Artificial Intelligence for Health care. He has given invited lecture topic Nanotechnology - based on ocular drug delivery system recent advances and future prospects as resource person & Chief guest in Sri Rangaboopathi College of Pharmacy Villupuram District. Tamilnadu. Currently he is doing research in the area of nanotechnology in Transdermal drug delivery, Cosmetic Technology system & herbal nanoformulation in various routes of drug delivery systems with academic contributions.

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Dr. Devi Thamizhanban, Doctorate in Pharmacy, having research experience in the field of Pharmaceutical Analysis for 15 years. Currently working as Professor in the Department of Pharmaceutical Chemistry at Chettinad School of Pharmaceutical Sciences, Chettinad Academy of Research and Education (CARE), Tamil Nadu, India. Her research experience includes industrial research in analytical method development and institutional research. Published more than 30 research publications in international journals and recognised reviewer for various reputed journals. Also holds 2 patents and 1 book chapter. Life member in Association of Pharmaceutical Teachers of India, Pharmacy council of India.