

## Editorial

# Space Medicine: Preparing the Human Body for Interplanetary Travel

Filippou Dimitrios

Ass. Professor, Medical School, National and Kapodestrian University of Athens

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In the stillness before humanity first ventured beyond Earth, a delicate inquiry stirred between heartbeats: could a human body withstand the harshness of space? From this profound wonder emerged the initial ideas of what would evolve into space medicine. In 1948, Hubertus Strughold—at the U.S. Air Force School of Aviation Medicine—introduced the term "space medicine," envisioning the medical framework essential for sustaining life outside our planet. His daring illustrations of airtight cabins, pressure suits, and "*Mars jars*" designed to replicate extraterrestrial atmospheres set the foundation for a discipline informed by both urgency and creativity.

That same year, the U.S. Air Force convened a symposium led by Brigadier General Harry Armstrong, where scientists and health professionals gathered to discuss numerous challenges, including cosmic radiation and the psychological impacts of isolation. This exchange—addressing concerns from solar flares to pilot health—seemed exotic to many, especially those who had tasted brief weightlessness in test aircraft. It paved the way for the establishment of a dedicated institution: the *Department of Space Medicine*, formed shortly thereafter. Concurrently, Soviet scientists were conducting similar research, launching animals into space, developing pressurized capsules, and laying the groundwork for Yuri Gagarin's orbital flight in April 1961. Gagarin's achievement confirmed a pivotal truth: humans could survive in space—but mere survival wouldn't be enough.

As the Gemini and Apollo programs advanced, medical inquiry became integral to every launch countdown. Researchers monitored astronauts for cardiovascular strain, tracked bone density and red blood cell fluctuations, and noted muscle atrophy.

Then, in 1973, Skylab launched—a pioneering laboratory in orbit. Crews spent extended periods in space; medical teams documented space motion sickness, fluid shifts, cardiovascular deconditioning, and bone loss, turning hypotheses into tangible data.

Amid these historic milestones was Dee O'Hara, the first aerospace nurse for NASA. She provided compassionate care to the Mercury Seven, drawing their blood, soothing their anxieties, and establishing trust, always present during launches and landings. Her role transcended mere monitoring; she cultivated camaraderie. Throughout the Gemini and Apollo programs, she navigated trauma and victories, transforming a realm of machinery into a domain of human connection. After Skylab, she advanced protocols for studies on bed rest and preventative care that continue to shape research on spaceflight effects today.

Meanwhile, aboard the Mir space station, cosmonauts endured months—and even over a year—in orbit, exposing deeper insights into health challenges: significant muscle loss, sensorimotor disarray, spinal elongation, and psychological strain exceeding what any single aircraft could mitigate. Gennady Padalka and Valeri Polyakov achieved remarkable durations in space; Polyakov returned after 437 days, demonstrating that while biology may bend, it can also rebound.

As the Cold War eased, space medicine gained institutional strength. In 1997, NASA established the National Space Biomedical Research Institute to enlist scientists in unraveling risks and solutions for long-duration missions. Analog investigations like Mars-500 evaluated mental effects of confinement, while subsequent organizations like TRISH (Translational Research Institute for Space

Health) ensured that findings would benefit both astronauts and terrestrial healthcare.

International collaborations emerged: Japan conducted meticulous bed-rest and dietary research, while China's Tiangong station examined cardiovascular responses, skin cell behavior, and mental fatigue with advanced imaging. Telehealth integrated astronauts into virtual medical consultations, long before Earth's remote clinics adopted similar strategies. The International Space Station, continuously occupied for over two decades, has become a vital hub for studying disease mechanisms, aging, immunology, and various health issues, all under the unique conditions of microgravity.

A particularly significant innovation was developed by Patricia Cowings, who created an autogenic-feedback exercise to combat space motion sickness. This biofeedback training—addressing heart rates, blood pressure, and neural control—enabled astronauts to adapt more quickly, a reminder of the importance of holistic care in the face of physical science.

The ongoing evolution of space medicine—shaped by NASA archival experts like Doarn, researchers in space psychology, physicians aboard shuttle missions, and local healthcare providers—illustrates how the seeds sown in 1948 burgeoned into a vibrant field straddling Earth and the cosmos, blending empathy with empirical diligence.

As we now anticipate missions to return to Artemis, construct lunar habitats, and explore Martian environments, we embrace this legacy. Space medicine has transformed from a speculative notion into both a protector and guide: it safeguards physical and mental well-being against cosmic challenges while illuminating paths for healthcare advancements on Earth. From life-supporting capsules and dedicated flight nurses to deep-space simulations and AI-assisted diagnoses, the field mirrors humanity's journey from wonderment to purposeful exploration.

Today, carrying adaptive courage and creative medical advancements forward, we seek not only to preserve life in orbit but to enhance its quality, whether tethered to Earth or reaching toward celestial destinations. In the grand saga of human discovery, the next horizon calls us beyond our world—and yet, our most significant challenges may dwell within ourselves. The human body, molded by Earth's gravity and safeguarded by its atmosphere and magnetic shield, now faces an environment for which it was never intended. It is space medicine that serves as both custodian and innovator, committed to maintaining our physiological integrity in the void while turning adversity into progress that illuminates life back on Earth.

To start, microgravity introduces a significant shift from the conditions our bodies have adapted to over millennia. Within days, notable effects become evident. The skeletal system, used to daily mechanical stresses, starts to lose bone mass at a rate not typically seen even in the elderly, with astronauts experiencing losses exceeding one percent monthly in space—far exceeding the usual age-related declines on Earth. At the same time, muscle atrophy manifests, especially in postural and gravitational muscles, leading to reduced strength and endurance. This deterioration results from disrupted protein balance and altered gene activity tied to muscle function. Additionally, as fluids shift upward, they raise intracranial pressure and contribute to vision issues now identified as Spaceflight-Associated Neuro-Ocular Syndrome (SANS).

Microgravity's effects do not stand alone. Cosmic radiation—from energetic galactic cosmic rays (GCRs) and sporadic solar particle events (SPEs)—sneaks past spacecraft shielding, engendering severe risks. Current protective technologies falter against heavy, high-energy particles, leaving body tissues exposed. The potential consequences include DNA damage, cancer risks, neurodegeneration, and alterations in the central nervous system due to impacts on neurogenesis. Intriguingly, the combined pressures of microgravity and radiation may exacerbate

immune dysfunction in ways that remain inadequately understood, highlighting the need for further investigation into their interplay.

Beyond the physical domain, the psychological resilience of astronauts also requires equal scrutiny. Isolation, confinement, disrupted sleep patterns, communication delays, and relentless mission demands create a formidable mental landscape. Research indicates that prolonged missions can provoke symptoms of depression, anxiety, cognitive decline, and shifts in emotional regulation—potentially through neuroplastic changes. While some studies suggest that cognitive abilities may adapt and remain relatively intact, subtler shifts—like slower processing speeds and occasional lapses in attention—are persistent, accompanied by improved emotional recognition. Once astronauts return to Earth, they often confront stress associated with readjustment, insomnia, interpersonal challenges, and shifts in identity as they reintegrate into a constantly evolving world.

The significant insights from the renowned Twins Study provide both caution and understanding. As astronaut Scott Kelly spent nearly a year aboard the ISS while his identical twin remained on Earth, researchers noted unexpected telomere elongation—an unusual stress response—alongside altered gene activity, increased inflammation, cardiovascular strain, and diminished cognitive speed and accuracy. Such findings underscore that even the most elite and prepared individuals remain considerably susceptible to the rigors of space.

In response to these challenges, space medicine is developing innovative countermeasures for musculoskeletal health. Resistive exercise regimens, centrifugation techniques, vibration therapy, and elastic gravity-simulating suits (like the "penguin suit") aim to recreate gravitational effects and reduce the loss of bone and muscle. Concurrently, pharmacological interventions—including bisphosphonates, hormone treatments, and amino acid supplementation—are under evaluation for their potential to preserve bone strength in microgravity.

Nutrition is a vital—though often overlooked—foundation of health preservation. Research in space nutrition highlights how macro- and micronutrients interact with immune function, musculoskeletal health, hormone regulation, and mental wellness. Key factors for mission success include the stability of nutrients over extended periods, the social significance of shared meals, and adjusting dietary needs to mitigate the impacts of radiation and microgravity.

Medication stability presents another challenge. Research indicates that many medications can degrade in spaceflight conditions, potentially becoming ineffective or unsafe during a roundtrip mission to Mars. Scientists are exploring solutions such as on-demand drug synthesis, more durable formulations, and the development of autonomous pharmaceutical manufacturing aboard spacecraft.

At the same time, advancements in radiation protection are underway. New strategies, including ingestible protectants and enhanced shielding materials, are being developed to minimize both cumulative and acute radiation exposure for crew members. These innovations not only benefit astronauts but also have implications for patients on Earth undergoing radiation treatment or working in hazardous environments.

Significant progress is also being made in remote health monitoring and personalized health systems. Space agencies aim to create an autonomous health platform that utilizes continuous biometric data, artificial intelligence, predictive analytics, and tailored decision-making for each crew member. This "Precision Space Health" framework is crucial for deep space missions where medical support from Earth may not be available.

Supporting these advancements, emerging wearable technologies—such as soft exosuits and sensor-equipped clothing—provide dynamic loading, real-time feedback on neuromuscular function, and adaptability for limited spaces. These lightweight systems could revolutionize both

countermeasures in space and rehabilitation for the elderly on Earth.

However, these technological advancements must address ethical considerations. Issues surrounding medical autonomy, the allocation of resources, informed consent in extreme situations, and equitable access to new treatments are fundamental questions in the ethics of space medicine—principles that should guide the design and implementation of health interventions in extraterrestrial contexts.

As we look toward Mars and beyond, the knowledge gained from the International Space Station and analogous settings benefits Earth. The biosensors used for astronauts' vital sign monitoring contribute to telemedicine and remote diagnostics in underserved regions. Radiation-protective substances may eventually shield patients undergoing chemotherapy. Wearable rehabilitation devices designed for space may aid in restoring mobility for frail individuals on Earth. Microgravity-grown organoid cultures can accelerate advancements in disease modeling and regenerative medicine before they even leave the atmosphere.

Yet, a pressing question persists: is investing in space medicine justifiable when urgent health issues exist on our planet? The response

emphasizes that space medicine serves as a force multiplier—not a distraction. Every advancement in remote care, biomonitoring, regenerative sciences, and bioengineering ultimately enhances life back on Earth. Few sectors demonstrate how necessity drives innovation more than in the pursuit of health in the absence of gravity.

As we gear up for exploration of the Moon, Mars, and beyond, space medicine acts as both shield and guide. It transforms the challenges of weightlessness into new perspectives on medicine, physiology, and our understanding of biological endurance. When we develop new supports for bones, ensure pharmaceuticals can withstand the void, and maintain cognitive stability under isolation, the benefits extend far beyond spacecraft and reach into every clinic, caring for remote patients and vulnerable populations here on Earth.

Ultimately, space medicine challenges us to do more than survive the void; it urges us to redefine health. Each mission to the stars becomes a journey of exploration—not just into space, but into the depths of our biology, creativity, and healing capacity, whether in orbit or at home. Regardless of gravity's pull, the lessons from our extraterrestrial endeavors persist, as impactful and transformative as the stars themselves.