ORIGINAL RESEARCH PAPER

Health Nursing

SPACE NURSING AND EXTREME ENVIRONMENTS: INNOVATIONS, CHALLENGES, AND FUTURE DIRECTIONS

KEY WORDS: Space Nursing, Aerospace Medicine, Astronaut Health, Microgravity, Telemedicine, Space Exploration.

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ABSTRACT

Space nursing is an evolving specialty within aerospace medicine that addresses the unique physiological, psychological, and operational challenges of human spaceflight. As missions extend to the Moon, Mars, and other deep-space destinations, nurses are expected to play a pivotal role in health monitoring, emergency management, and crew well-being in resource-limited and high-risk environments. This review explores current innovations such as telemedicine, wearable biosensors, portable diagnostics, and AI-assisted decision-making that support autonomous medical care in microgravity and radiation-prone settings. Key challenges include the absence of immediate Earth-based medical support, limited onboard equipment, and the need for specialized training to integrate clinical expertise with space mission protocols. Future directions emphasize interdisciplinary collaboration, development of compact medical technologies, and incorporation of aerospace medicine into nursing education to prepare practitioners for autonomous healthcare delivery in extreme environments. Space nursing will be central to safeguarding astronaut health and enabling sustained human presence beyond Earth.

INTRODUCTION

As human spaceflight evolves from brief missions to extended deep-space exploration, ensuring effective healthcare delivery in microgravity becomes increasingly vital. Nurses, with their strong background in patient care and crisis response, hold an essential role in supporting astronaut health. Incorporating nursing expertise into space medicine provides comprehensive care, encompassing both preventive measures and emergency interventions.[1]

Space nursing is a specialized field focused on assessing astronauts' medical readiness for missions, training NASA personnel to manage in-orbit medical situations, and studying how spaceflight impacts the human body. Originating during the 1960s space race, the profession has steadily expanded in both workforce and knowledge. Ongoing research by aerospace medical experts has driven major advancements in disease treatment on Earth, while continuous innovation in this discipline enhances the effectiveness of space medicine.[2]

METHODOLOGY

A comprehensive literature review was conducted by systematically searching multiple international databases, including Web of Science (WoS), MEDLINE via PubMed, Scopus, SciELO, CINAHL-EBSCO, and Google Scholar. A structured search strategy was developed in advance, utilizing key descriptors such as "Astronauts," "Space Flight," and "Nursing in Care." Boolean operators "AND" and "OR" were applied to refine and broaden the retrieval process as appropriate. The review considered publications in both English and Spanish, without imposing restrictions on the type of document (e.g., original research, reviews, case studies, conference proceedings) or the year of publication. This inclusive approach ensured that the analysis captured both historical perspectives and the most recent developments in the field of space nursing.

HISTORY

Since the advent of commercial aviation in the 1920s, nurses have been integral to the fields of aviation and flight medicine, providing in-flight care and supporting the health of pilots, crew, and passengers during early long-distance air travel. Their role naturally extended to aerospace medicine as humanity prepared to venture beyond Earth.

In 1958, President Dwight D. Eisenhower signed the National Aeronautics and Space Act, establishing NASA to lead the United States into the space age. Recognizing the need for comprehensive medical oversight, the agency actively recruited nurses to collaborate with physicians, biomedical scientists, and engineers in assessing astronaut health and mission readiness. These nurses conducted physical examinations, monitored vital signs, and contributed to the rigorous medical screening process that ensured only the fittest individuals were cleared for space missions.[3]

Beyond pre-mission evaluations, nurses played a pivotal role in post-flight recovery. They carefully documented and analyzed physiological changes such as weight loss, fluid redistribution, cardiovascular adaptations, and muscle atrophy that astronauts experienced upon returning from microgravity. Their observations not only informed NASA's understanding of spaceflight's impact on human physiology but also guided the development of countermeasures—like exercise regimens and dietary protocols—to protect astronaut health on future missions.

This early integration of nursing into aerospace programs laid the foundation for space nursing as a specialty, highlighting its importance in advancing both space medicine and earthbound healthcare innovations.[4]

SPACE NURSING AND THEORIES

Neuman's Systems Model in Space Nursing

Core Concept:

Neuman's Systems Model conceptualizes the human body as an open system constantly interacting with internal and external stressors. In this framework, the nurse's responsibility is to preserve system stability by anticipating, reducing, or managing these stressors.

Application to Space Nursing:

Physiological Stressors: Conditions such as microgravity lead to muscle wasting, fluid redistribution, and reduced immune defenses. Space nurses implement targetedcountermeasures including structured exercise programs, the use of compression garments, and careful nutritional oversight.

Psychological Stressors: Prolonged isolation, restricted environments, and circadian rhythm disturbances affect mental well-being. Nurses provide virtual counseling, mental health monitoring, and interventions such as light therapy to support healthy sleep cycles.

Primary Prevention: Pre-mission training programs are developed to help astronauts adapt to anticipated space-related challenges.

Secondary Prevention: Advanced technologies like remote health monitoring and AI-assisted diagnostics enable early identification of potential medical issues.

Tertiary Prevention: Comprehensive rehabilitation protocols are used after missions to aid astronauts in readjusting to Earth's gravity and restoring musculoskeletal strength.

Why This Theory Fits:
Neuman's model is well suited to space nursing because it emphasizes protecting and maintaining astronaut stability when exposed to complex, high-risk, and constantly changing stressors encountered during spaceflight.[5]

Orem's Self-Care Deficit Nursing Theory in Space Nursing

Core Concept
Orem's theory emphasizes that when individuals are unable to meet their own self-care needs, nurses intervene to provide the necessary assistance until the individual can regain independence.

Application to Space Nursing:
Self-Care Deficits in Space: In microgravity, astronauts often face challenges in performing routine health tasks such as administering injections, dressing wounds, or handling medical emergencies.

Nursing Interventions:

- **Total Compensation:** When astronauts are completely incapacitated—for example, due to severe space motion sickness or decompression illness—nurses provide full care to ensure stabilization.

- **Partial Compensation:** Nurses employ AI-enabled monitoring and robotic systems to assist astronauts in performing essential self-care tasks.

- **Supportive-Educative Care:** Before launch, astronauts receive targeted training from nurses to develop basic health management skills that can be applied during missions.

Why this theory fits:
Orem's model is particularly applicable to space nursing because astronauts frequently experience temporary limitations in self-care. Guided by this framework, nursing interventions help sustain astronaut health and operational efficiency throughout space missions.[6,7]

Application of Watson's Theory to Space Nursing

1. Creating a Healing Environment in Space

- Space presents a high-stress, high-risk setting where astronauts face isolation from loved ones as well as numerous physiological and psychological challenges.

- Using Watson's "Carative Factors," space nurses work to foster a human-centered, supportive atmosphere aboard spacecraft and space stations. This may involve virtual reality tools for relaxation, facilitating meaningful interactions among crew members, and encouraging mindfulness practices to maintain emotional stability.[8]

2. Providing Holistic Care for Astronauts

- Watson's theory defines health as a dynamic balance between body, mind, and spirit. In space nursing:

- **Physical well-being:** Nurses monitor vital signs, address bone density reduction, and oversee dietary regimens.

- **Mental and emotional support:** Interventions include stress management programs, telehealth counselling, and strategies to mitigate feelings of isolation.

- **Spiritual wellness:** Practices such as meditation, mindfulness routines, or individualized wellness plans are adapted to astronauts' personal beliefs.[9]

3. Building Nurse-Astronaut Trust and Connection

- Whether interacting through telemedicine or onboard during future missions, space nurses must establish empathy and trust.

- By applying Watson's caring principles, nurses develop authentic, supportive relationships with astronauts, helping them feel emotionally anchored despite the vast distance from Earth.

4. Advancing Health Beyond Medical Treatment

- Watson's model highlights that nursing extends beyond treating illness to fostering overall well-being. Space nurses implement preventive measures such as:
- Encouraging daily mental health exercises.
- Using AI-based health coaching for emotional and psychological support.
- Designing reintegration programs to help astronauts transition smoothly back to Earth's gravity and lifestyle post-mission.

Why Watson's Theory Fits Space Nursing

- Space nursing requires more than clinical interventions; it demands promoting psychological and emotional resilience in extreme environments.
- Watson's focus on caring relationships, whole-person health, and mind-body-spirit harmony aligns seamlessly with the unique needs of astronauts on long-duration missions.[10]

PHYSIOLOGICAL CHALLENGES IN SPACE NURSING

Astronauts undergo profound physiological changes during space missions due to the absence of gravity, prolonged confinement, and exposure to space radiation. Space nurses must understand these adaptations to design preventive measures, monitor health changes, and manage complications effectively. Key physiological concerns include:

- **Musculoskeletal Atrophy:** Extended exposure to microgravity causes a significant reduction in muscle mass and bone mineral density. Without the constant gravitational load of Earth, weight-bearing muscles weaken and bones become fragile, increasing the risk of fractures both during spaceflight and after returning to Earth. Space nurses collaborate with flight surgeons and exercise specialists to implement resistive exercise regimens, monitor musculoskeletal health, and recommend nutritional support such as calcium and vitamin D supplementation.

- **Cardiovascular Adaptations:** In microgravity, fluids shift toward the upper body and head, altering circulation and reducing cardiac workload. This redistribution can lead to reduced blood volume, diminished orthostatic tolerance, and dizziness or fainting upon re-entry to Earth's gravity.

Space nurses monitor cardiovascular health through telemetric systems, assess vital parameters, and support interventions like fluid loading or the use of lower body negative pressure devices to maintain circulatory stability.

- **Immune System Suppression:** Spaceflight is associated with dysregulation of immune function, making astronauts more susceptible to infections and slower wound healing. Nurses monitor immune biomarkers, ensure proper hygiene practices aboard spacecraft, and assist in the use of immune-supportive nutritional strategies to maintain astronaut resilience.

- **Neurovestibular Issues:** The lack of gravitational cues affects the vestibular system, leading to space motion sickness, spatial disorientation, and impaired balance. These issues can compromise crew performance during critical operations. Space nurses assist with preventive measures, such as gradual adaptation protocols, medication management, and exercises that retrain balance systems during and after missions.[11]

PSYCHOLOGICAL AND BEHAVIORAL HEALTH CONSIDERATIONS

Mental and emotional health is just as vital as physical well-being during long-duration space missions. The confined, isolated, and high-risk environment of spaceflight places unique psychological demands on astronauts. Space nurses provide continuous monitoring, counselling, and interventions to preserve crew morale and cognitive performance. Key considerations include:

- **Isolation and Confinement Stress:** Extended periods away from family, friends, and Earthly surroundings can result in loneliness, anxiety, and depressive symptoms. Space nurses use telehealth platforms for counselling, encourage positive communication between crew and ground teams, and facilitate morale-building activities to reduce feelings of detachment.

- **Circadian Rhythm Disruptions:** With multiple sunrises and sunsets occurring each day in orbit, astronauts often experience disturbed sleep-wake cycles. Sleep deprivation leads to fatigue, irritability, and impaired decision-making. Nurses recommend sleep hygiene practices, such as timed light exposure, regulated work-rest schedules, and in some cases, controlled use of sleep aids to maintain optimal alertness and performance.

- **Team Dynamics and Conflict Management:** Living and working in close quarters under stressful conditions can lead to interpersonal friction. Maintaining a consistent team atmosphere is crucial for mission achievement. Space nurses support training in emotional intelligence, conflict resolution strategies, and peer support systems to strengthen collaboration and reduce stress-induced tension.

By addressing both physiological changes and psychological stressors, space nurses play an indispensable role in safeguarding astronaut health, ensuring mission efficiency, and facilitating successful reintegration upon return to Earth.[12]

INNOVATIONS IN SPACE NURSING

Advances in space technology have transformed how nurses deliver healthcare to astronauts, making it possible to provide timely, efficient, and precise care even in microgravity. These innovations enhance both preventive health measures and emergency medical management during space missions:

Telemedicine and Remote Monitoring:

Space nurses now use telehealth platforms integrated with AI-powered diagnostic tools to continuously track astronauts' health status. These systems allow real-time transmission of vital signs, laboratory data, and imaging results to Earth-based medical teams. Artificial intelligence assists in early detection of abnormalities, providing decision support for immediate interventions and ensuring astronauts receive expert care regardless of distance.

Portable Diagnostic Devices:

Miniaturized, lightweight medical equipment designed for microgravity enables astronauts and space nurses to perform on-the-spot diagnostic tests. Handheld ultrasound devices, compact blood analyzers, and lab-on-a-chip technology provide rapid results for conditions such as infections, metabolic imbalances, or cardiovascular irregularities. These point-of-care solutions reduce reliance on Earth-based laboratories and make diagnosis faster and more reliable in orbit.

Automated Medication Delivery Systems:

Smart medication dispensers programmed with precise dosage schedules help ensure astronauts receive the correct medication at the right time, even during busy mission phases. These systems reduce the risk of human error, track medication adherence, and can adjust dosages based on biometric feedback gathered through remote monitoring devices.

Virtual Reality (VR) for Training and Mental Health Support:

VR platforms serve a dual purpose in space nursing. For medical readiness, they simulate realistic clinical scenarios, helping astronauts practice emergency procedures in an immersive environment. For psychological well-being, VR-based therapy programs offer stress reduction, mood enhancement, and a sense of connection to familiar Earth environments, counteracting isolation and confinement during long-duration missions.

Together, these technological innovations not only improve the quality and safety of in-flight healthcare but also prepare astronauts to manage health issues autonomously when immediate ground support is limited. Space nursing, enhanced by these tools, ensures astronauts can remain healthy, resilient, and mission-ready throughout deep-space exploration.[12]

TRAINING AND ROLE OF SPACE NURSES

Space nurses require extensive interdisciplinary training, including:

- **Aerospace Medicine in addition Space Physiology:** Considerate space-related health subjects.
- **Emergency and Critical Care Training:** Managing trauma, decompression sickness, and other emergencies.
- **Technical Proficiency in Medical Robotics and AI:** Utilizing robotic assistance for medical interventions.

Before Spaceflight

- Tracking and assessing astronauts' vital signs and body measurements.
- Performing routine health evaluations before launch, during missions, and upon return.
- Establishing contingency protocols for managing injuries in orbit, within the spacecraft cabin, and during transport.
- Supporting mission readiness through comprehensive physical assessments and participation in pre-flight medical research
- Acknowledging and respecting cultural identity, traditions, and beliefs to strengthen crew cohesion.
- Delivering health education programs and promoting overall well-being among crew members.
- Providing training in first aid techniques and emergency response.
- Overseeing and coordinating the vaccination schedule for astronauts.

- Designing nursing care plans aligned with the framework of 14 universal human needs.
- Ensuring the reliability and accuracy of medical equipment and biosensors through systematic verification based on crew–machine interface principles.

During Spaceflight

- Support crew adaptation by maintaining physiological stability in response to microgravity conditions.
- Perform continuous surveillance of spacecraft environmental parameters such as oxygen concentration, air quality, and humidity, while minimizing crew exposure to airborne particles and managing closed-loop life support systems.
- Work jointly with specialists to provide nutritional guidance, develop tailored diets, ensure appropriate hydration, and administer vitamin supplementation during missions and extravehicular activities (EVAs).
- Oversee safe handling of bodily waste, including water recovery and proper disposal of solid excreta.
- Plan, implement, and assess exercise regimens—incorporating aerobic, flexibility, strength, and resistance training using devices like treadmills, cycle ergometers, and resistive equipment—to prevent muscle wasting and bone loss.
- Develop and monitor artificial gravity protocols to counteract fluid redistribution and related physiological effects.
- Track and regulate circadian rhythms, ensuring proper rest periods and integrating schedules for meditation, social engagement, and work tasks.
- Maintain hygiene by ensuring regular cleaning and disinfection of spacecraft interiors, while promoting personal cleanliness to limit microbial transmission in confined environments.
- Establish procedures for evaluating and preparing spacesuits, confirming garment integrity and operational readiness before every EVA.
- Identify potential environmental hazards onboard and create strategies to mitigate associated risks.
- Manage and maintain records on crew health status for ongoing evaluation.
- Review and refine contingency plans to address unexpected medical emergencies.
- Deliver psychological support to improve morale, reduce anxiety, and prevent interpersonal conflicts, irritability, depression, or other mood disturbances.
- Safeguard personal privacy and incorporate recreational opportunities to relieve stress in isolated conditions.
- Foster health awareness and preventive practices specific to space environments.
- Detect, monitor, and document any occupational injuries or illnesses occurring during missions.
- Design and implement care protocols for rapid assessment and management of emerging conditions or injuries in orbit.
- Donate to preventive health agendas addressing dental care, vision care, and hearing protection.
- Develop medication delivery systems tailored for microgravity, ensuring proper intravenous administration without reliance on gravity flow.
- Assess pharmaceuticals for their pharmacokinetics, pharmacodynamics, microbiomics interactions, and safety profile under spaceflight conditions.
- Identify behavioural or psychological changes among crew members and introduce measures to maintain healthy interpersonal relationships and provide recreational outlets for optimal mental well-being.

After Spaceflight

Monitoring and regulation of vital parameters:

- Continuous tracking of body temperature, heart rate, blood pressure, and respiratory rate during re-entry and post-flight.
- Early identification of physiological stress or cardiovascular instability caused by the transition from microgravity to Earth's gravity.

Management of syncope and orthostatic intolerance:

- Observation and control of fainting episodes and difficulty adjusting to upright posture after space missions.
- Use of graded re-acclimatization techniques, mobility assistance, and real-time hemodynamic monitoring to stabilize astronauts.

Musculoskeletal assessment and rehabilitation support:

- Evaluation of muscle strength, joint mobility, and bone density after spaceflight.
- Implementation of targeted rehabilitation programs, including strength training, balance therapy, and sensorimotor re-training.

Medical supply oversight and logistics management:

- Ensuring sufficient availability of medical consumables throughout the mission.
- Maintaining accurate records of usage, planning timely replacements, and submitting expense reports for resource accountability.

HEALTH PROBLEMS AND RISKS IN SPACE

During space exploration, astronauts face unusual and even catastrophic threats ; we have been able to identify some of them that can become medical emergencies that compromise the lives and safety of travelers. These glitches can go ignored within the ISS and throughout the recital of EVA. One way to predict these situations is by analyzing the probability of occurrence and it is classified as follows:

Mild

Space adaptation syndrome, Space Motion Sickness (SMS), vomiting, dizziness, gastrointestinal symptoms , severe malaise , headache, joint pains , tiredness, fatigue , uncomplicated urinary tract infection , upper respiratory tract infection , simple lacerations, muscle strains , sprains , anxiety and depression .

Moderate

Medical conditions of concern in space like potential issues include the presence of gas emboli within the heart and blood vessels due to spacesuit decompression, disturbances in heart rhythm (cardiac arrhythmias), uncomplicated heart attacks (myocardial infarction), perforation of the duodenal wall (duodenal ulcer), respiratory distress syndromes, kidney stones (nephrolithiasis), diverticulitis, appendicitis, penetrating chest injuries, traumatic head injuries, extensive burns affecting more than 40% of the body surface, bone fractures, space-related anemia, severe urinary tract infections, hemorrhages leading to hemodynamic instability, exposure to ionizing radiation, and severe (grade III) ligament sprains.

Severe

Explosive spacesuit decompression, micro- meteorite accidents, severe concussions , sepsis, shock, and complicated cardiac arrhythmias.

FIRST SPACE NURSES

Lieutenant Dolores “Dee” O'Hara (born in 1935) and Lieutenant Shirley Sineath were the first nurses tasked with providing medical care to NASA's original seven astronauts in Project Mercury. Lt. O'Hara served as the program's official staff nurse, while Lt. Sineath worked as a surgical nurse on the astronaut recovery team. Before joining NASA, O'Hara worked as a registered nurse in the labor and delivery unit at Patrick Air Force Base in Cape Canaveral, Florida. In 1959, Colonel Knauf, the hospital commander, invited her to join Project Mercury as a nurse—a position she accepted without hesitation.

NASA selected O'Hara in part because they believed she could build the astronauts' confidence. At the time, astronauts were often more comfortable sharing health issues with nurses than with flight surgeons, who had the authority to ground them for medical reasons. In a 2002 interview, O'Hara explained that her responsibilities included boarding recovery vessels, setting up compact medical stations for emergencies, preparing treatment kits for potential astronaut injuries, and conducting pre-flight health assessments such as measuring height, weight, blood pressure, and temperature.

After years of service supporting astronaut health, O'Hara transitioned in 1974 to become manager of the Human Research Facility at NASA's Ames Research Center, where she worked until her retirement in 1997.[14]

CAREER PATH AND NECESSARY QUALIFICATIONS

In 1962, NASA introduced the Space Nursing Program, requiring all applicants to hold a bachelor's degree in nursing—a standard that continues today. Career pathways into aerospace medicine at NASA generally follow two routes. The military path involves service in the U.S. Air Force, which provides an aerospace medicine residency at Wright-Patterson Air Force Base in Ohio, or in the U.S. Navy, which runs a similar program at the Naval Aerospace Medical Institute in Pensacola, Florida. The civilian path typically consists of completing specialized university-level coursework followed by a one-month clerkship at NASA, usually available to medical students in their final year. At present, only Wright State University, the University of Texas Medical Branch at Galveston, and the Mayo Clinic offer accredited aerospace medicine programs in the United States.

MEDICAL COMPLICATIONS SURROUNDING SPACE TRAVEL

Difficulties emerging throughout or upon return from space flight

- Lightheadedness
- Worsening of proprioception (capability to intellect the crusade and location of ones body)
- Slower wound healing
- Immune system suppression
- Muscle atrophy
- Reduction in bone density
- Facial swelling
- Height increas
- Low blood pressure
- Fainting
- Blurred vision
- Poor nutrition: weight loss, dehydratio
- Disruption to sleep pattern
- Fatigue
- Poor coordination
- Possible decreased fertility

Complications that can develop years later

- Cancer due to radiation
- Hyperthyroidis
- Cataracts

FUTURE DIRECTIONS

The future of space nursing will involve:

- **Artificial Gravity and Advanced Life Support Systems:** To mitigate physiological deconditioning.
- **Long-Term Medical Facilities on the Moon and Mars:** Establishing extraterrestrial hospitals for extended missions
- **Genomic and Biotechnological Innovations:** Personalized medicine tailored for space environments
- **Interdisciplinary Collaboration:** Strengthening partnerships between nursing, medicine, engineering, and space agencies to enhance astronaut health.[15]

CONCLUSION

Space nursing is an emerging yet critical component of human spaceflight, providing specialized and comprehensive medical support to astronauts throughout all stages of a mission. Unlike conventional nursing, it addresses the unique physiological and psychological challenges posed by microgravity, radiation exposure, confined living spaces, and limited medical resources. As human space exploration expands toward longer missions on the Moon, Mars, and beyond, nurses will play a pivotal role in developing and implementing innovative healthcare protocols, conducting real-time health monitoring, managing medical emergencies, and supporting crew mental well-being. To meet these demands, space nursing will increasingly rely on telemedicine, portable diagnostic devices, artificial intelligence, and autonomous care systems that allow for effective decision-making even when communication with Earth is delayed. Ongoing and future research is essential to optimize astronaut health, improve training programs, and design adaptable medical technologies that can function in extreme and resource-limited environments. By integrating clinical expertise with aerospace medicine and technological innovation, nurses will be central to sustaining human presence beyond Earth and advancing the frontiers of nursing practice itself.

LIST OF ABBREVIATIONS

AsMA	-Aerospace Medical Association
CINAHL	-Cumulative Index to Nursing and Allied Health Literature
DeCS	-Health Science Descriptors
EVA	-Extravehicular Activities
HAdEES	-Space Exploration Analog Habitat – Colombia
ICP	-Increased Intracranial Pressure
IOP	-Increased Intraocular Pressure
ISS	-International Space Station
MeSH	-Medical Subject Headings
NASA	-National Aeronautics and Space Administration
QCRI	-Qatar Computing Research Institute
SciELO	-Scientific Electronic Library Online
SLS	-Space Launch System
SMS	-Space Motion Sickness
SNS	-Space Nursing Society
WoS	-Web of Science

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