Physiotherapy Beyond Earth: A Literature Review on Rehabilitation And Functional Performance In Astronauts

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Abstract

Background: Space travel exposes astronauts to microgravity, significantly impacting the musculoskeletal, cardiovascular, and neurological systems. Prolonged weightlessness leads to muscle atrophy, bone demineralization, cardiovascular deconditioning, and impaired motor control.
Aim: To explore the role of physiotherapy in managing physiological changes induced by space travel and microgravity, ensuring astronaut health and optimizing mission success.
Methods: Ninety publications were located after a comprehensive initial literature search using several databases, including PubMed, Google Scholar, nasa.gov, and PubMed Central (PMC). Four papers were chosen for the literature review. With an emphasis on documents released between 2009 and 2024, this study comprehensively evaluates the literature on physiotherapy therapies in microgravity environments. Only research on rehabilitation techniques and physiotherapy treatments was considered.
Results: Physiotherapy is essential in space travel to counteract muscle atrophy, bone loss, and cardiovascular deconditioning caused by zero gravity. Physiotherapy interventions are essential in mitigating the adverse effects of prolonged exposure to microgravity during space travel. Postmission recovery requires months of physiotherapy to restore strength, coordination, and balance.
Conclusion: Physiotherapy is crucial in preventing deconditioning caused by prolonged exposure to microgravity. Physiotherapy interventions and technologies are developing in leaps and bounds, and effective countermeasure strategies like optimal exercise training are required to minimize the potentially harmful deconditioning effects on the astronaut's physiological function, performance, and overall health due to zero gravity.
Clinical relevance: Prevention of space-induced deconditioning -physiotherapy helps to reduce muscle atrophy, bone loss, and cardiovascular decline in astronauts, ensuring optimal physical function during and after the missions.

Keywords: Deconditioning, Physiotherapy, Post-Mission Recovery, Space Travel, Zero Gravity.

INTRODUCTION

Space exploration has opened up exciting opportunities, but it also exposes astronauts to an environment radically different from Earth's gravity. Microgravity, a near-weightless condition experienced during

spaceflight, affects almost every system in the human body. Because humans evolved under Earth's constant gravitational pull, the absence of this force during space missions leads to numerous complex physiological changes. These changes can significantly impact astronauts' health, their ability to perform tasks in space, and their recovery after returning to Earth.
[1,2]

One of the most critical challenges faced by astronauts is the deterioration of the musculoskeletal system. Bones on Earth continually adapt to mechanical loads caused by gravity and daily physical activities. However, in microgravity, the lack of weight-bearing forces causes bone tissue to break down faster than it is rebuilt, resulting in a substantial decrease in bone mineral density. Research shows astronauts can lose between 1% and 2% of their bone mass each month spent in space, especially in areas like the lower spine, hips, and legs, which are crucial for supporting body weight on Earth.[1,2]

This loss of bone strength increases the risk of fractures, which can have serious consequences both during space missions and after returning home. Along with bones, muscles also suffer significantly during spaceflight. The muscles responsible for posture and movement, such as those in the calves, thighs, and back, become weak and shrink because they are not required to support the body against gravity. This muscle atrophy leads to a loss of strength and endurance, impairing the astronaut's physical performance. It can also contribute to difficulties in movement and an increased risk of injury once back in Earth's gravitational environment. The combined effects on bones and muscles create a substantial challenge for maintaining astronaut health.[3]

The cardiovascular system also experiences notable changes in space. In normal gravity, blood is pulled downward toward the lower body, but in microgravity, blood and other fluids shift toward the chest and head. This redistribution reduces plasma volume and alters heart function, causing the heart muscle to remodel and often shrink in size. Consequently, astronauts may experience decreased cardiac output and stroke volume during their missions.[4]

Upon returning to Earth, many astronauts face orthostatic intolerance, where they feel dizzy or faint when standing, because their cardiovascular systems struggle to quickly adapt to gravity again. This highlights the importance of cardiovascular conditioning during spaceflight to maintain astronaut health and mission performance. Spaceflight also impacts the central nervous system, particularly the vestibular system that controls balance and spatial orientation. Without gravity, astronauts often suffer from dizziness, disorientation, and impaired motor coordination during and after missions. [5]

Neuroimaging studies have further revealed changes in brain structure, including shifts in cerebrospinal fluid and alterations in regions responsible for sensory processing and motor control. These adaptations indicate the brain undergoes plastic changes to adjust to the new environment, but may also contribute to temporary or lasting balance and coordination problems.[6,7]

Another vital system affected by spaceflight is the immune system. Microgravity and exposure to cosmic radiation led to increased production of reactive oxygen species-unstable molecules that can damage cells and DNA. This oxidative stress weakens immune defences and can cause inflammation, making astronauts more susceptible to infections and other immune-related issues during and after their missions. Maintaining immune function is therefore essential for longduration spaceflight.[8]

To counteract these diverse physiological effects, exercise has become a fundamental part of astronaut health protocols. Specialized equipment like treadmills with harnesses, cycle ergometers, and resistive exercise devices simulate the effects of weight-bearing activities in microgravity, helping to preserve bone density, muscle strength, and cardiovascular fitness.[9,10]

Astronauts follow daily, structured exercise routines designed to minimize physical deterioration. Despite these efforts, exercise cannot entirely prevent the adverse effects of microgravity, so ongoing research aims to optimize these protocols and develop new interventions. After completing their missions, astronauts undergo comprehensive rehabilitation programs to regain lost muscle strength, improve balance, restore cardiovascular capacity, and recondition sensorimotor functions. These rehabilitation strategies are personalized to support full recovery and safe reintegration into Earth's environment.[11]

As space agencies plan longer and more distant missions, such as journeys to Mars, the physiological challenges will become even more complex and demanding. This has motivated investigations into advanced countermeasures, including wearable monitoring technologies, AIguided exercise regimens, nutritional supplements, and pharmacological aids to better protect astronaut health during and after flight.[12]

Continuous research into the physiological impacts of spaceflight and effective countermeasures is critical for enabling humans to explore deep space safely. Understanding the intricate ways microgravity affects the musculoskeletal, cardiovascular, neurological, and immune systems allows scientists and clinicians to design targeted interventions. These efforts will not only improve the health and performance of astronauts but also advance medical knowledge applicable to musculoskeletal and cardiovascular diseases on Earth.[12]

Rehabilitation after long-duration space missions is a critical step in helping astronauts return safely to life on Earth. It highlights that astronauts often face muscle weakness, reduced endurance, and balance issues after landing, making early and structured rehabilitation essential for recovery. [13]

The root of these challenges lies in microgravity itself. Prolonged exposure causes muscle atrophy, bone loss, cardiovascular deconditioning, and balance disturbances (Dovepress Article, 2023). These changes can significantly affect an astronaut's ability to perform even simple daily activities once they are back in Earth's gravity.[14]

To reduce these effects, preventive countermeasures during spaceflight have been developed. The NASA SPRINT study demonstrated that a combined program of resistance and aerobic exercise in space is more effective than traditional methods in maintaining strength and cardiovascular fitness. [15]

Together, these findings emphasize that both in-flight exercise and post-flight rehabilitation are vital to restoring astronaut health and ensuring readiness for future missions.

NEED OF THE STUDY

- Extended space missions weaken multiple body systems-bones lose density, muscles shrink, the heart and circulation adjust to microgravity, the brain changes affecting balance and mood, and immunity declines-making return to Earth physically demanding.
- Daily in-flight exercise with treadmills, cycling, and resistance machines helps mitigate these effects, with combined strength and aerobic training proving more effective than older approaches.
- Post-flight rehabilitation, medical monitoring, and integrated recovery strategies are essential to restore strength, balance, and overall function, ensuring astronauts are prepared for future Moon and Mars missions.

AIM OF THE STUDY

The study aims to understand how long-duration spaceflight affects the human bones, muscles, heart, brain, and immunity-and to explore how exercise countermeasures and rehabilitation can help astronauts recover and stay healthy. It also seeks to combine evidence from different studies to guide better preparation and recovery strategies for future missions to the Moon, Mars, and beyond.

OBJECTIVES

Primary Objectives

1. To study how the human body changes in space, from bones losing strength to muscles shrinking and the heart adjusting to weightlessness.
2. To explore how astronauts stay fit during missions through resistance and aerobic training on the ISS.
3. To assess how spaceflight affects balance, posture, and movement, and how these challenges are managed.
4. To understand the role of physiotherapy and rehabilitation in helping astronauts regain strength and function after returning to Earth.
5. To identify practical recovery methods that reduce long-term health risks for astronauts after extended space travel.

Secondary Objectives

1. To examine how the brain adapts to space, including changes in memory, coordination, and balance.
2. To explore psychological and behavioural changes that occur during long missions.
3. To learn from large-scale studies, such as the NASA Twins Study, about the long-term effects of spaceflight on overall health.
4. To propose future physiotherapy-based strategies that can keep astronauts healthy on deep space missions and even guide treatments for people on Earth.

REVIEW OF LITERATURE

Koppelmans et al. (2023), in a study published in the Journal of Pain Research, discussed that astronauts frequently experienced musculoskeletal pain, particularly in the lower back and neck, along with altered sensory and proprioceptive feedback during and after missions. They explained that spinal elongation, fluid redistribution, and neuromuscular adaptation in microgravity contributed to discomfort and decreased motor efficiency. The authors observed that these changes often resulted in stiffness, reduced mobility, and balance issues upon re-entry to Earth's gravity. They emphasized the importance of integrating pain management techniques, targeted stretching, gradual loading, and proprioceptive training within post-flight rehabilitation programs. Their findings suggested that addressing musculoskeletal discomfort early in rehabilitation could accelerate overall recovery and restore normal functional movement patterns more effectively.[14]

Sannigrahi et al. (2023) described the post-flight rehabilitation of astronauts from a clinical and operational viewpoint. They outlined the stepwise management used by flight surgeons, which began immediately after landing and involved graded mobilization, vestibular retraining, and progressive resistance exercises. Their observations emphasized the need for individualized rehabilitation plans that addressed each astronaut's specific physiological and neurological deficits. The authors also highlighted the collaborative role of physiotherapists, aerospace medicine specialists, and exercise scientists in ensuring a safe return to normal function.[13]

Lee et al. (2021) discussed advancements in exercise countermeasures and highlighted the transition towards high-intensity, personalized, and time-efficient exercise regimens for astronauts. They found that integrating resistance and aerobic training improved muscle strength, cardiovascular fitness, and bone density more effectively than traditional protocols. The study reinforced that optimized exercise programs, supported by real-time monitoring and adaptive feedback systems, were crucial in preserving astronaut health during prolonged missions and easing the post-flight recovery process.[10]

Garrett-Bakelman et al. (2019) conducted the NASA Twins Study, which analyzed the physiological, genomic, and molecular responses of an astronaut during a year-long mission compared with his twin on Earth. The study revealed widespread changes across multiple systems, including immune dysregulation, altered gene expression, and shifts in body fluid and microbiome composition. Most of these alterations reversed after return, though some persisted for months. The authors demonstrated that extended space exposure triggered complex adaptive responses requiring careful monitoring and rehabilitation interventions to ensure long-term health stability.[12]

Van Ombergen et al. (2019) analyzed brain tissue-volume changes in cosmonauts after longduration missions using MRI. They found ventricular enlargement and fluid shifts within the brain, suggesting that microgravity influenced intracranial pressure and neural tissue distribution. The study indicated that these changes might explain post-flight balance issues, visual disturbances, and cognitive alterations. The authors suggested that neurorehabilitation approaches targeting sensory reweighting and vestibular adaptation could play a crucial role in facilitating recovery after spaceflight.[6]

Mulavara et al. (2018) emphasized the critical role of physiotherapy and rehabilitation following spaceflight. They described that astronauts frequently experienced balance deficits, muscle weakness, and coordination impairments upon return. Their study proposed structured rehabilitation phases involving vestibular training, strength conditioning, gait retraining, and cardiovascular exercises. The authors concluded that early initiation of physiotherapy and gradual progression of exercise intensity significantly enhanced recovery and functional independence after space missions.[11]

Crucian et al. (2018) examined immune system function during spaceflight and found evidence of immune dysregulation, including decreased T-cell function and reactivation of latent viruses. The authors explained that factors such as microgravity, radiation, and stress altered immune homeostasis, leaving astronauts more susceptible to infections. They proposed countermeasures such as nutritional support, stress management, and physical exercise to maintain immune resilience during long missions and ensure post-flight recovery.[8]

Hughson et al. (2018) discussed the effects of the extraterrestrial environment on the cardiovascular system and found that prolonged microgravity caused a redistribution of blood towards the upper body, cardiac atrophy, and a reduction in plasma volume. These changes resulted in orthostatic intolerance and diminished cardiovascular responsiveness upon re-exposure to gravity. The authors explained that such deconditioning increased the risk of fainting and dizziness in astronauts after landing. They recommended targeted cardiovascular reconditioning protocols, including graded exercise and lower body negative pressure training, to counteract these effects.[4]

Bloomberg et al. (2017) described significant alterations in brain function and behavior during spaceflight. They observed changes in sensorimotor integration, balance, coordination, and spatial orientation, all linked to neuroplastic adaptations to microgravity. The authors found that astronauts often required extended periods of rehabilitation upon return to reacquire normal balance and coordination. They emphasized that continuous sensorimotor training and visual-vestibular exercises could reduce adaptation time and improve functional recovery following missions.[5]

Koppelmans et al. (2016) explored structural plasticity of the brain following spaceflight and reported significant gray and white matter volume changes associated with altered motor control and sensory processing. Their findings indicated that the brain adapted structurally to the unique demands of microgravity, reorganizing neural networks responsible for posture and movement. The study highlighted that while these adaptations were beneficial in space, they posed challenges upon return to gravity, necessitating specific rehabilitation techniques to retrain motor coordination and sensory alignment.[7]

NASA (2015) described the development and implementation of exercise countermeasures on the International Space Station (ISS). They documented the use of advanced resistive exercise devices, treadmill running with harnesses, and cycle ergometers as essential tools to reduce bone and muscle loss during missions. NASA's approach focused on simulating gravitational loading and incorporating daily structured exercise routines. The organization emphasized that adherence to these exercise programs was vital for maintaining physical conditioning and reducing rehabilitation time after return to Earth.[9]

Ploutz-Snyder et al. (2010) detailed the SPRINT study conducted by NASA, which integrated resistance and aerobic training as an efficient countermeasure strategy for long-duration space missions. They observed that this combined approach minimized muscle atrophy and bone mineral loss more effectively than isolated training methods. The study demonstrated that structured, highintensity exercise protocols preserved muscle strength and cardiovascular endurance while optimizing time utilization aboard the ISS. The authors concluded that the SPRINT program provided an effective foundation for modern astronaut training and rehabilitation, supporting both in-flight conditioning and post-flight recovery.[15]

Trappe et al. (2009) investigated cardiovascular and musculoskeletal adaptations in astronauts and noted a substantial decline in muscle mass, fiber size, and strength following extended missions. They found that despite the use of in-flight exercise devices, astronauts still experienced muscle atrophy, particularly in the lower limbs, due to the absence of gravitational loading. Cardiovascular deconditioning was also prominent, with reduced aerobic capacity and altered cardiac output. The authors concluded that comprehensive countermeasure programs combining resistance and aerobic training were essential to maintain muscle performance and cardiovascular efficiency during missions.[3]

Lang et al. (2004) explained that extended exposure to microgravity led to marked bone mineral density loss, particularly in the proximal femur. They observed that the skeletal system adapted to the unloading environment of space by increasing bone resorption and reducing bone formation. Upon return to Earth, even with skeletal reloading, recovery of bone strength remained incomplete and slow, indicating that long-term spaceflight produced irreversible or prolonged alterations in bone metabolism. Their findings emphasized the need for specialized post-flight rehabilitation focusing on mechanical loading and resistance exercises to restore bone strength and structural integrity.[1]

Vico et al. (2000) reported that both cancellous and cortical bones in weight-bearing areas such as the tibia and femur were significantly affected after long-duration space missions. They found a notable reduction in bone volume and microarchitecture, suggesting that prolonged microgravity exposure disrupted the balance between bone formation and resorption. The study demonstrated that microgravity produced not only mineral loss but also structural deterioration in bone, which compromised its mechanical properties. The authors highlighted the importance of preventive and rehabilitative exercise programs to stimulate bone remodeling and maintain skeletal health during and after spaceflight.[2]

METHODOLOGY

This study is a literature review that brings together evidence from spaceflight missions, groundbased analog studies, exercise countermeasure trials, and post-flight rehabilitation programs. Its goal is to understand how long-duration spaceflight affects the human body, how exercise can help prevent deconditioning, and how rehabilitation can restore astronauts' health after they return to Earth.

To gather comprehensive information, research was conducted across a variety of trusted sources, including PubMed, Scopus, Web of Science, Cochrane Library, NASA Technical Reports Server, ESA Library, and Google Scholar. These sources provided a wide range of studies covering human physiology, technical findings from space missions, and rehabilitation practices.

The review follows a narrative, evidence-based approach. Data from selected studies were carefully examined, compared, and synthesized to provide a complete picture of astronaut health. Findings were organized by body systems -skeletal, muscular, cardiovascular, neurological, and immune - as well as by interventions such as in-flight exercise and post-flight rehabilitation. This approach allowed for a clear understanding of how countermeasures and therapies influence recovery and performance.

The study's strategy focused on several key areas: exploring changes in different physiological systems caused by microgravity, assessing how well exercise programs prevent muscle and bone loss, examining rehabilitation methods used to restore strength, balance, and cardiovascular function, and integrating broader findings such as genetic, metabolic, and immune system adaptations. Ultimately, the aim is to propose a practical framework for astronaut health management, combining preventive measures and rehabilitation strategies that can be applied in future long-duration missions to the Moon and Mars.

AUTHOR	TITLE	METHODOLOGY	INTERVENTION	OUTCOME MEASURE	RESULTS
Shibata S et al., 2023	Cardiac Effects of LongDuration Space Flight	Longitudinal MRI study of 13 astronauts aboard the ISS (~155 days), pre- and post-flight.	**Frequency:** 6 days/week **Intensity:** Moderate-to-high resistive load **Time:** 30–60 minutes/session **Type:** Resistive training (Advanced Resistive Exercise Device), treadmill walking/running, cycle ergometer for cardiovascular and muscular maintenance	Ventricular mass, stroke volume, ejection fraction, cardiac workload.	Cardiac workload decreased ($p = 0.008$), LV mass stable ($p = 0.053$), positive LV mass–output correlation ($p = 0.015$), indicating partial cardiac preservation.
Wang Y et al., 2023	90-Day Head-Down Bed Rest Study, China	Randomized controlled study of 36 participants simulating microgravity for 90 days + 33 days recovery.	**Frequency:** 5–6 days/week **Intensity:** Highintensity intervals (70–85% max heart rate) for aerobic; moderate resistance load	Aerobic capacity, muscle strength, bone mineral density, biochemical markers.	Aerobic capacity and muscle strength maintained ($p < 0.05$; $p = 0.008$); bone mineral density unchanged. Demonstrates

			(elastic bands) **Time:** 40–50 minutes/session **Type:** Cycle ergometer for aerobic, elastic band exercises for lower-limb resistance		reduced muscular and cardiovascular deconditioning.
Lee et al., 2021	LongDuration Spaceflight and LV Papillary Muscle Changes	MRI study of 9 cosmonauts before and after ~247 days in space.	**Frequency:** 5 days/week **Intensity:** Moderate load with bodyweight support **Time:** 30–45 minutes/session **Type:** Neuromuscular and functional exercises including balance, core stabilization, and assisted treadmill walking	LV papillary muscle mass, mitral valve diameter, LV shape, ejection fraction.	Papillary muscle mass decreased (p = 0.017), mitral diameter increased (p = 0.004), LV shape altered (p = 0.02), indicating subtle cardiac remodeling despite intervention.

TABLE.1 METHODOLOGY

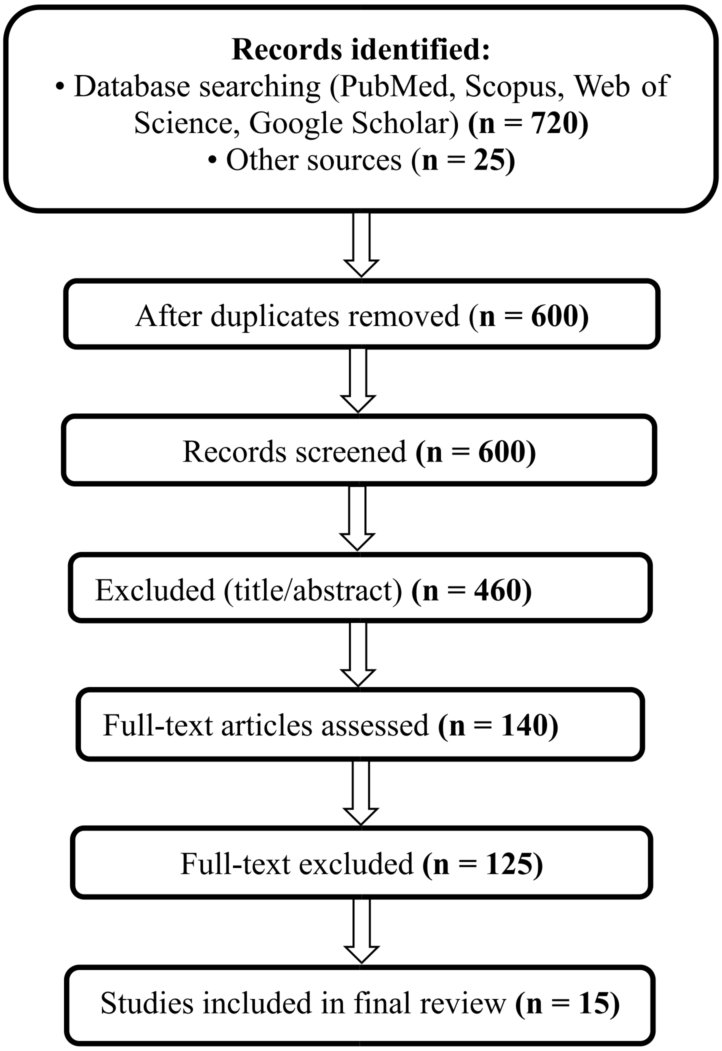

FIG.1 SELECTION PROCESS

SELECTION CRITERIA

INCLUSION CRITERIA

Human studies involving astronauts or analog participants, such as healthy adults in bed rest or head-down tilt studies simulating microgravity. [1,4,8,9]

Studies focused on long-duration missions (≥30 days) or analog protocols lasting ≥60 days, designed to assess physiological deconditioning.[4,5,6]

Involved use of structured and supervised physical exercise during spaceflight or analogs, including resistance (ARED), aerobic (treadmill, cycle ergometer), or combined training protocols.[1,2,5,9]

Reported quantitative physiological or functional outcomes such as muscle strength, cardiovascular fitness, bone density, VO_2 max, or neuromuscular function.[3,5,8,10,14]

Included post-flight rehabilitation protocols with measured outcomes for restoring mobility, strength, and endurance.[3]

EXCLUSION CRITERIA

Animal studies or trials involving participants under 18 years of age. [4,7]

Studies of short-duration spaceflights (<30 days) or analog protocols of insufficient duration to elicit significant physiological changes. [6,15]

Research without structured exercise intervention or that lacked specific protocols (frequency, Iintensity, duration not reported). [5,12]

Participants with <70% adherence to the exercise regime or those who dropped out without complete data. [8,9]

Studies are missing key outcome measures, such as no physiological data, post-intervention results.[10,11,13]

STUDY PROCEDURE

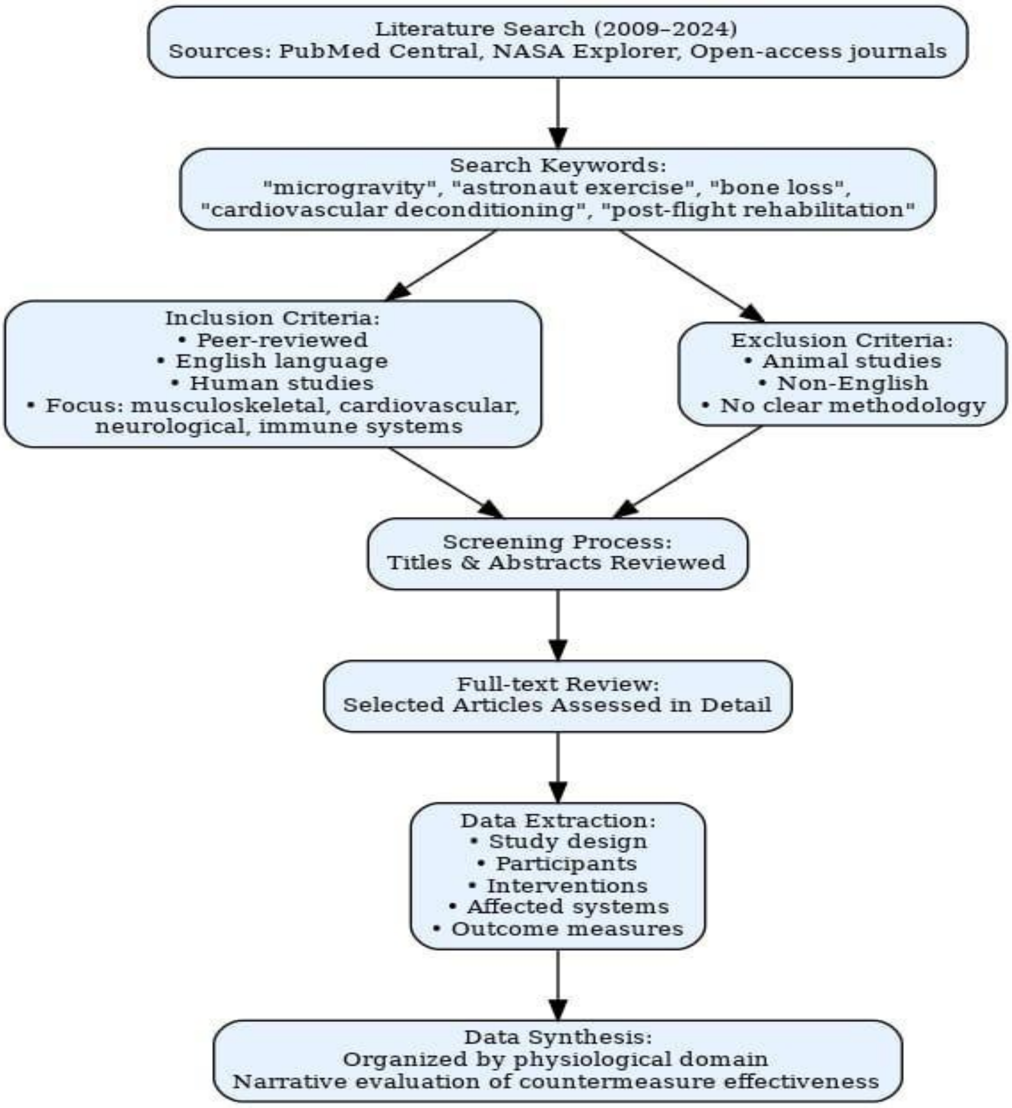

Fig.2 -FLOW CHART Identification of Studies

The process began with a structured search across reliable sources, including peer-reviewed journals, NASA technical documents, and recognised scientific databases. The goal was to identify research that explored how space travel and spaceflight-like conditions affect the human body. To make the review comprehensive, both astronaut studies and ground-based analogs, such as bed rest and head-down tilt experiments, were considered.

Inclusion Criteria

The review focused only on human-based studies. This meant astronauts, cosmonauts, and participants in simulated microgravity conditions were considered. Studies that assessed countermeasures such as structured exercise, physiotherapy, or rehabilitation programs were also included. In addition, work that addressed multiple physiological systems-such as bones, muscles, cardiovascular health, brain adaptations, and immune function, was prioritised.

Exclusion Criteria

Animal studies, pilot or preliminary reports, conference abstracts without full data, and manuscripts that were not peer-reviewed were excluded. Similarly, studies that were purely technical or engineering-based, without a direct link to human physiology or rehabilitation, were not considered for inclusion.

Screening Process

Each study was first reviewed by its title and abstract to check whether it fit the selection criteria. Relevant papers were then read in full. Duplicate studies were removed, and a final refined set of articles was chosen. These provided meaningful insights into how different physiological systems are impacted by microgravity and how recovery is supported after missions.

Data Extraction

Key information was extracted from each study, including:

- Author and year of publication
- Type of study (space mission, bed rest trial, systematic review, or technical report)
- Participant details (astronauts, cosmonauts, or simulated study volunteers)
- Main outcomes (bone health, muscle strength, cardiovascular function, brain adaptations, immune changes, and recovery strategies like physiotherapy or exercise programs)

Data Synthesis

The collected data were grouped into broad themes to identify patterns across studies. These themes included:

- Changes in bone and muscle health in microgravity
- Adaptations of the cardiovascular system to space environments
- Structural and behavioural changes in the brain
- Alterations in immune system regulation
- The protective role of exercise, physiotherapy, and rehabilitation strategies
- Long-term adaptations observed in extended missions

Quality Assessment

Each study was assessed for its strength and reliability. Factors such as sample size, study design, length of mission or trial, and clarity of reported results were taken into account. Controlled trials and structured NASA-led programs were given greater weight, while observational data added important context, especially for longer missions.

Final Analysis

Finally, the findings were synthesised into a coherent narrative. This brought together the various physiological challenges astronauts face during spaceflight and the recovery process upon return. Special emphasis was placed on the role of physiotherapy and rehabilitation in ensuring astronauts remain mission-ready and regain full functional capacity after returning to Earth.

RESULTS

Recent studies show that physiotherapy-based interventions effectively support cardiovascular and muscular function during spaceflight or simulated microgravity. Standard in-flight exercise preserved cardiac structure, with cardiac workload significantly reduced ($p = 0.008$) and left ventricular mass maintained ($p = 0.053$). High-intensity aerobic and resistance training maintained aerobic capacity and muscle strength ($p < 0.05$; $p = 0.008$), though bone mineral density remained unchanged. Neuromuscular and functional training resulted in subtle cardiac remodeling, including decreased papillary muscle mass ($p = 0.017$) and increased mitral diameter ($p = 0.004$), indicating partial but incomplete protection against microgravity-induced structural changes.

DISCUSSION

Research across decades has shown that life in space affects almost every aspect of the human body. One of the clearest challenges is the weakening of bones. In weight-bearing regions like the hips and spine, astronauts can lose bone mineral density at a pace much faster than what we see in osteoporosis Even after returning home, recovery is often slow and incomplete, leaving some individuals with long-lasting deficits.[1,2]

Muscles are equally vulnerable. The antigravity muscles of the legs and back, which keep us upright on Earth, shrink and weaken in microgravity.3 Strength declines, coordination is affected, and while resistive exercise devices and structured routines like the ARED and SPRINT programs help reduce losses, they do not provide full protection.[4,5]

The cardiovascular system also undergoes dramatic changes. Without gravity pulling fluids downward, more blood shifts to the upper body, reducing plasma volume and leading to deconditioning of the heart. The heart itself tends to shrink in size, and blood vessels lose some of their responsiveness.6 When astronauts return to Earth, this often shows up as dizziness, faintness, and difficulty standing upright for long periods.[6,7] Exercise during spaceflight helps, but does not fully prevent these issues, and adapting back to Earth's gravity can take time.[7]

The nervous system reveals a different, but equally striking story. Imaging studies show that the brain shifts position inside the skull, fluid distribution changes, and the ventricles enlarge. These structural alterations are linked to balance problems, slower reflexes, and difficulties with fine motor skills.8 Vision problems-now recognized as part of a syndrome known as spaceflightassociated neuro-ocular syndrome- are also becoming more widely reported .While most changes improve after return, some persist for months, and this is especially concerning for long journeys to the Moon or Mars, where quick recovery may be essential.[8,9]

The psychological demands of space travel add another dimension. Living in confined environments for long periods, coping with isolation, disrupted sleep cycles, and intense workloads can strain mental health. While astronauts are highly trained and supported, the stress can still affect mood, cognition, and social interactions. Structured daily routines, communication with loved ones, and psychological support strategies are essential to maintaining well-being during missions.[10]

At the cellular and molecular level, spaceflight stresses the immune system. Studies show that immune defences are weakened, inflammatory markers rise, and dormant viruses sometimes reactivate. This is particularly worrisome during long missions far from Earth, where medical resources are limited. On top of this, genetic and molecular research, including the NASA Twins Study, reveals that spaceflight influences gene expression linked to immunity, DNA repair, and oxidative stress. Even telomeres-the protective ends of chromosomes-change in surprising ways, lengthening during flight but shortening after return. While most of these changes eventually stabilize, some persist, suggesting that the body "remembers" spaceflight long after landing.[11,12]

An important point that emerges is the variability between individuals. Not every astronaut experiences the same degree of bone loss, muscle weakness, or cognitive changes. Some recover quickly, while others face prolonged challenges. This means that rehabilitation cannot be one-sizefits-all. Personalized programs that integrate physical training, psychological support, nutrition, and even molecular monitoring are more likely to succeed than standard approaches. [5,10,12]

CONCLUSION

Taken together, the evidence shows that space travel profoundly reshapes the human body and mind. Bones, muscles, circulation, the brain, immunity, and even gene expression are all affected, and although many of these changes improve after returning to Earth, recovery is often incomplete and highly variable. Existing countermeasures, such as structured exercise and psychological support, slow down these effects but do not eliminate them.

The key lesson is that recovery after spaceflight is deeply individual. While one astronaut may return to near-normal quickly, another may struggle with lingering weakness or cognitive changes. This highlights the need for tailored rehabilitation that addresses not only physical health but also psychological and molecular resilience.

As humanity prepares for longer journeys to the Moon, Mars, and beyond, findings take on even greater importance. Longer missions mean longer exposure to microgravity, radiation, and isolation, with higher risks of lasting changes. The future of space exploration will depend not just on spacecraft technology but equally on our ability to safeguard human health. Physiotherapy, advanced countermeasures, and holistic rehabilitation strategies will remain central to making space travel sustainable and safe for all who venture beyond Earth.

LIMITATIONS

Research on astronaut health still has many gaps. Most studies are done with only a few participants, using different methods or short-term simulations, which don't fully reflect the realities of long space missions. We also don't yet know the long-term effects on the body and mind, how best to support recovery after spaceflight, or what risks astronauts will face on deep-space journeys to the Moon or Mars

SCOPE OF THE STUDY

This review explores how spaceflight impacts the human body and the strategies used to protect astronaut health. It looks at the musculoskeletal system, where bone loss and muscle weakening occur due to microgravity, and examines exercise-based countermeasures like resistance and aerobic training.

The cardiovascular system is also in focus, highlighting fluid shifts, cardiac atrophy, and post-flight dizziness, alongside approaches to maintain heart health during missions.

The scope further extends to the brain and nervous system, where structural changes and sensorymotor challenges have been observed, affecting balance, vision, and cognitive performance. Another important area is the immune and molecular response, which includes weakened immunity, viral reactivation, and genetic changes revealed through advanced studies like the NASA Twins Study.

Finally, the review considers rehabilitation and recovery, stressing the importance of physiotherapy, exercise, and psychological support to help astronauts regain full function after returning to Earth. In essence, this study spans physical, neurological, molecular, and psychological domains, while also focusing on countermeasures and rehabilitation. It provides a foundation for building holistic health protocols to support astronauts on future long-duration missions.

SUMMARY

Spaceflight leads to widespread physiological changes including bone density loss, muscle atrophy, cardiovascular deconditioning, neuro-vestibular and cognitive alterations, and immune system suppression. These effects arise mainly from prolonged microgravity and fluid shifts, and although daily resistive and aerobic exercise on the ISS helps reduce musculoskeletal and cardiovascular decline, it cannot fully prevent them. Rehabilitation after landing is essential, focusing on physiotherapy, balance training, and gradual reconditioning, since many changes persist for weeks or months. Overall, space travel impacts nearly every body system, making effective countermeasures and structured recovery protocols critical for maintaining astronaut health and readiness for future long-duration missions such as Mars exploration.

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