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The Study of Nutritional Requirements and Physiological Changes in Space Station

V. Sabeetha[1,]*, A. Lokeshwari[2]

Abstract

This article focuses on the impact of physiological adaptations to weightlessness on nutrient and food requirements in space. These modifications entail reductions in body water and plasma volume, which affect the cardiovascular and renal systems. Spaceflight poses intricate and predominantly detrimental effects on the human body, spanning both short and long durations. Long-term weightlessness leads to significant issues like muscle atrophy, skeletal deterioration, cardiovascular function deceleration, reduced red blood cell production (space anemia), balance and eyesight disorders, immune system alterations, fluid redistribution causing a "moon-face" appearance, body mass loss, nasal congestion, sleep disturbances, and excessive flatulence. Research on engineering challenges for space travel and propulsion systems dates back a century, with recent emphasis on understanding how humans can endure extended space missions. November 2019 findings highlighted serious blood flow and clot problems in astronauts during a six-month study on the International Space Station. Challenges in mitigating hazards like weightlessness, characterized as a microgravity environment, involve addressing proprioception loss, fluid distribution changes, and musculoskeletal system deterioration. Additionally, changes in bone mass contribute to the increased risk of forming renal stones due to higher urinary calcium concentrations. There are several aspects of nutrition in space, including providing essential nutrients and maintaining the health of the immune, musculoskeletal, and endocrine systems. Furthermore, a thorough analysis is conducted on the effects of environmental elements such as radiation, temperature fluctuations, and atmospheric pressures on nutrition in space. Precisely calculating the nutritional amounts required to maintain health and mitigate the effects of microgravity is essential, especially for long-term space missions.

Keywords: Physiological changes, space station, muscle mass, nutrition in space, metabolism

INTRODUCTION

The daily requirements for protein, lipids, carbs, minerals, trace elements, fat-soluble vitamins, and different water-soluble vitamins must be satisfied by space nutrition. It is important to note that space foods often have high sodium content due to processing and the need for long-term preservation [1]. However, this elevated sodium intake may have adverse physiological effects, such as increased urinary calcium excretion and a higher risk of kidney stones. Weightlessness affects multiple bodily systems, including the bones, muscles, cardiovascular system, and nervous system [2]. Maintaining proper caloric intake during space flight involves various factors such as energy requirements, changes in taste and satiety caused by physiological alterations, time management for meal preparation, consumption, and clean up, food quality, and even food availability. The differences in fuel composition (protein, carbs, and fats) during spaceflight and their impact on energy consumption have not received much attention.

*__Author for Correspondence__
V. Sabeetha
E-mail: sabeethaveluvrts@gmail.com

[1,2]Master of Science Students, Department of Food and Nutrition, Periyar University, Salem, Tamilnadu, India

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Additionally, the spacecraft, space environment, and weightlessness itself all influence human physiology. Ensuring access to potable water, clean air, and effective waste disposal systems are necessary for maintaining a habitable ecosystem. Adequate energy intake is crucial in astronaut nutrition as it is not only more important than other nutritional factors but also leads to reasonable consumption of other essential nutrients if energy needs are met [3].

PHYSIOLOGICAL CHANGES DURING SPACE MISSION

Changes in Bone Mass

In the microgravity environment of spaceflight, there is a notable increase in bone reabsorption, while bone formation either remains unchanged or experiences a slight decrease. As a result, the net outcome is a loss of bone mass [4]. It is particularly crucial to address bone loss, especially in the lower extremities, during space missions lasting more than thirty days, as the duration of time spent in space amplifies the extent of bone loss. Additionally, weightlessness contributes to an increase in calcium excretion through urine and raises the risk of developing kidney stones, both of which are associated with bone loss. Maintaining calcium levels and bone metabolism are significant concerns for astronauts, and ground-based experiments simulating spaceflight have generated a vast body of research to complement the limited data obtained from actual missions [5].

CHANGES IN MUSCLE MASS

The consistent observation in the history of spaceflight has been a reduction in body weight, usually ranging from 1 percent to 5 percent, but in some cases, it can even reach 10 percent to 15 percent of preflight body mass. While a 1 percent loss may be attributed to dehydration, the majority of the weight loss stems from the depletion of muscle and fat tissues. Microgravity exposure leads to a decline in muscle mass, volume, and performance, particularly in the legs, impacting both short and long-duration flights [6].

ENDOCRINE SYSTEM FUNCTION

The conditions encountered during space travel seem to elicit a sensitive reaction from the endocrine system. Various hormones, such as epinephrine, norepinephrine, adrenocorticotropin, and cortisol, may increase in circulation as part of the stress response to microgravity [7]. These hormones contribute to increased blood levels of fatty acids and glucose, increased breakdown of fats in adipose tissue, decreased synthesis of fat, and increased liver glycogen storage.

Measurements taken during and after space missions reveal heightened levels of catabolic hormones like cortisol and glucagon, along with prolonged 3-methylhistidine excretion, indicating a chronic metabolic stress response influenced by mission length, energy intake, exercise routine, and even gender [8]. These changes may have an impact on the immune system, muscle and bone mass loss, and the equilibrium of body fluids and electrolytes, which in turn may impact the cardiovascular response to microgravity.

GASTROINTESTINAL FUNCTION

Astronauts undergoing space missions encounter early gastrointestinal changes, marked by the occurrence of a gaseous stomach due to the hindered upward movement of gases. Microgravity effects are thought to modify the interaction of gastric contents with gastrointestinal mucus. Cephalic fluid shifts, coupled with prevalent dehydration, may impact gastrointestinal motility by diminishing splanchnic flow. Prolonged inactivity contributes to increased transit time and potential alterations in gastrointestinal microflora. Exploring the incorporation of probiotics and prebiotics into space foods could offer potential benefits in enhancing gastrointestinal integrity and bacterial balance [9–10].

CARDIOVASCULAR HEALTH AND NUTRITION IN SPACE

While cardiovascular concerns loom large for those journeying through space, the intricate relationship between nutrition and cardiovascular adaptation remains largely unexplored. Notably, ongoing or planned studies aboard the ISS aim to illuminate this aspect in the coming years. While the positive effects of Omega-3 fatty acids on cardiovascular health are well-established on Earth, their impact during space flight remains uncharted territory [11]. Nevertheless, the current initiatives to enhance astronauts' intake of fish and Omega-3 fatty acids, primarily aimed at benefiting other physiological systems like bone and muscle, hold promising potential for cardiovascular well-being in space as well.

IRON METABOLISM DURING SPACE FLIGHT

Space exploration has consistently revealed hematologic shifts in astronauts, marked by space flight-induced anemia. This phenomenon, impacting the levels of circulating red blood cells and plasma volume, leads to a notable 10% to 15% reduction in circulatory volume. This adaptive response to weightlessness involves the removal of freshly released blood cells from circulation.

Notably, iron metabolism undergoes significant changes during prolonged space flights. Iron availability experiences an increase, accompanied by a rise in iron stores. Understanding these hematologic alterations is crucial for assessing the potential long-term health implications for astronauts navigating the challenges of extended space missions [12].

OXIDATIVE STRESS AND SPACE FLIGHT

Oxidative stress is heightened during space flight, primarily due to elevated solar radiation and low-wavelength electromagnetic radiation, even with spacecraft shielding. These environmental factors induce the formation of reactive free radicals in the human body, leading to oxidative damage in lipids, proteins, and DNA. Recent findings indicate an increase in oxidant damage post-flight, likely attributed to heightened metabolic activity and a decline in antioxidant defenses during the mission. This impact is more pronounced after extended space travel, with effects persisting for several weeks upon return. Human subjects exhibit elevated lipid peroxidation in erythrocyte membranes, a decrease in blood antioxidants, and increased urinary excretion of oxidative damage markers for lipids and DNA [13].

THE PROVISION OF NUTRITIONAL REQUIREMENTS OF FOOD IN SPACE

Current Space Food Systems

In the realm of current space food systems, the Hazard Analysis Critical Point Control legal framework, established to identify and mitigate food hazards, has become a standard in the industry. From the Apollo missions' use of dehydrated foods in the 1960s to the diverse menu on the International Space Station since 2000, advancements have shaped a 50/50 American and Russian food system. Nutrition guidelines, developed by leading experts, ensure astronauts receive adequate nutrients during long-duration spaceflight, mirroring macronutrient ratios on Earth [14].

PROVISION OF SUFFICIENT FOOD FROM THE START

Ensuring a steady food supply is crucial for extended space missions. For instance, astronauts typically require 1.8 kg of food daily, amounting to approximately 24,000 pounds or 10 tonnes for a 4-person crew on a round trip to Mars. Innovations by private companies like SpaceX, with reusable rockets, have significantly reduced costs, making it more feasible to transport ample food supplies for extended space travel.

DEVELOPMENT OF SYSTEMS TO GENERATE FOOD DURING THE MISSION

In the realm of sustainable nutrition for extended space missions, a promising regenerative approach involves cultivating nutrient-rich photosynthetic bacteria like Spirulina (Arthrospira platensis and Arthrospira maxima). With a history of use as a nutritional supplement, Spirulina boasts carbohydrates, lipids, proteins, essential amino acids, vitamins, minerals, and phytonutrients. The consumption of Spirulina biomass could revolutionize space sustenance by eliminating the need for prolonged shelf-life foods, minimizing packaging requirements, and resulting in a substantial cost reduction of approximately 38%, especially when considering a mixed menu of wet food for extended missions to Mars [15–16].

CONCLUSION

In conclusion, sustaining astronauts on extended space missions necessitates meticulous planning for a 5-year food storage, prioritizing nutrient-rich options to avert potential health crises. Emphasis should be placed on crafting diets that not only address individual nutritional needs but also accommodate diverse food preferences and cultural backgrounds of crew members. Efforts to enhance dietary adequacy, food safety, and psychological well-being are crucial to mitigate adverse physiological changes during prolonged space exploration.

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