The Role of Nutritional Research in the Success of Human Space Flight[1,2]

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ABSTRACT

The United States has had human space flight programs for >50 y and has had a continued presence in space since 2000. Providing nutritious and safe food is imperative for astronauts because space travelers are totally dependent on launched food. Space flight research topics have included energy, protein, nutritional aspects of bone and muscle health, and vision issues related to 1-carbon metabolism. Research has shown that energy needs during flight are similar to energy needs on Earth. Low energy intakes affect protein turnover. The type of dietary protein is also important for bone health, plant-based protein being more efficacious than animal protein. Bone loss is greatly ameliorated with adequate intakes of energy and vitamin D, along with routine resistive exercise. Astronauts with lower plasma folate concentrations may be more susceptible to vision changes. Foods for space flight were developed initially by the U.S. Air Force School of Aerospace Medicine in conjunction with the U.S. Army Natick Laboratories and NASA. Hazard Analysis Critical Control Point safety standards were specifically developed for space feeding. Prepackaged foods for the International Space Station were originally high in sodium (5300 mg/d), but NASA has recently reformulated >90 foods to reduce sodium intake to 3000 mg/d. Food development has improved nutritional quality as well as safety and acceptability. *Adv. Nutr. 4: 521–523, 2013.*

Introduction

The U.S. human space flight programs have launched nutritious and safe food (1,2) and required it to contain nutrients that facilitated physiological adaptation to weightlessness and psychological adaptation to extreme environments as well as act as a countermeasure to ameliorate the negative effects of space flight.

Energy

The composition of the United States baseline diet (i.e., percentage of calories from protein, carbohydrate, and fat) is generally acceptable for space flight. The International Space Station (ISS) menu provides ∼50% of calories as carbohydrate, 17% as protein, and 31% as fat (2). However, historically, food and energy intakes during flight were generally lower than before flight (2), despite data indicating that in-flight and preflight energy requirements are similar and that with intense exercise these requirements are higher during flight than before flight (1,2). The World Health Organization predictions of energy requirements for moderately active individuals seem to predict in-flight requirements and have thus been used as a standard for menu planning. The gap between energy intake and expenditure is further widened with the prescribed exercise countermeasures.

The total energy expenditure of space shuttle astronauts before and during space flight was determined using the doubly labeled water technique, and in-flight energy expenditure was shown to be similar to preflight expenditure or, in some cases, even higher, most likely as a result of increased exercise (1,2). Recently, a European Space Agency–sponsored experiment to study energy expenditure on long-duration flights has been initiated on the ISS.

Protein and Muscle

Exposure to microgravity reduces muscle mass and volume and performance, especially in the legs, on both short and long flights (2). During short-duration space flight, stable isotope turnover studies have indicated that whole-body protein turnover increased, accompanied by elevations in protein synthesis and even greater increases in protein breakdown.

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In studies with United States astronauts flying for long durations (>100 d) on the Russian Mir space station, protein synthesis was directly correlated with energy intake in 6 of the 7 astronauts studied, suggesting that the reduced protein synthesis is related to inadequate energy intake (3).

Bone and Muscle

A recent study, using heavy resistive exercise as a countermeasure to bone loss, for the first time showed that adequate energy, protein, and vitamin D supply are mandatory to maintain bone mineral density after 6 mo of space flight (4). However, dietary factors may still play a role in optimizing bone health. For example, high sodium intake has bone-resorbing effects during inactivity such as bed rest. When a very high NaCl intake (550 mmol/d) was consumed during bed rest, the increase in bone resorption markers was dramatically higher than it would have been because of immobility alone (5). This effect may be induced by a low-grade metabolic acidosis (5), which may activate osteoclasts. Potassium bicarbonate supplementation partly mitigates this effect on bone resorption (6).

The ratio of dietary protein to potassium intake might also affect bone turnover. Animal protein usually has a high content of sulfur-containing amino acids, and animals have a lower content of potassium (and potassium salts) than plants. Oxidation of sulfur-containing amino acids may lead to a low-grade metabolic acidosis and respective bone resorption. This resorption can be compensated for by decreasing the ratio of animal protein to potassium, in particular toward the end of a bed rest study (7).

Vision

An important aspect of space flight that presented recently is the vision-related issues seen in some of the astronauts flown to the ISS (8). Although the present hypothesis is that these changes are most likely induced by prolonged exposure to the effects of cephalad fluid shifts, evidence exists that these observed changes could also be related to alterations in the folate- and vitamin B-12–dependent, 1-carbon metabolic pathway involving homocysteine, cystathionine, 2-methyl citric acid , and methyl malonic acid (8). Before flight, the astronauts who suffered vision changes after landing had lower serum folate as well as much higher plasma homocysteine, cystathionine, 2-methyl citric acid, and methyl malonic acid concentrations than astronauts whose vision did not change, suggesting an association between vision changes and higher concentrations of intermediates in the pathway. Differences in this pathway may influence anatomic or physiologic susceptibility to environmental stressors such as fluid shifts or response to cabin CO_2. These studies suggested that polymorphisms in enzymes of this pathway may interact with microgravity to cause these pathophysiologic changes, and this possibility warrants further study.

Space Food Development

Early space food development began at the U.S. Air Force School of Aerospace Medicine. Dehydrated foods and cubes were developed in conjunction with the U.S. Army Natick Laboratories, which developed formulation, processing, and packaging specifications. On Mercury and Gemini flights, the food supplied was exclusively dried food, with most products requiring water for rehydration. Menu items were expanded for Apollo flights by adding thermostabilized pouches, canned fruits, and irradiated meats; reversibly compressed freeze-dried foods were also developed for these missions. Hazard Analysis Critical Control Point, developed for space flight, set safety standards. The "spoonbowl" package, introduced on Apollo missions, allowed use of ordinary utensils.

Skylab was the first United States space station, and its program included the first metabolic study conducted in space. Food quality was considerably improved over that of previous missions. A freezer and refrigerator allowed use of frozen and refrigerated foods. As a result, nutrient intake was near 100%, better than on all previous and many later missions.

Space shuttle fuel cells used to produce electricity provided an abundance of water as a by-product, which was utilized for food rehydration and thus helped to conserve overall food weight. The shuttle food system reverted to an Apollo type with increased food selection (1,9) but no refrigeration.

Meal selection on early shuttle missions started with a set menu for all crew members and a pantry for substitutions and snacks. Astronauts wanted the ability to choose their entrees at mealtime rather than 6 mo before the mission. The meals were stowed either by meal (e.g., all breakfasts together) or by individual crew member (i.e., each having his or her own container); also included were thermostabilized meals ready to eat obtained from the U.S. military. Today the ISS food is provided according to a planned menu but is stowed as a pantry, so that crew members can choose their meals at mealtime.

ISS prepackaged food was originally high in sodium (5300 mg/d). However, as mentioned previously, high sodium intake exacerbates bone loss and potentially exacerbates intracranial pressure–induced vision changes. NASA has reformulated 90 foods to reduce sodium intake to 3000 mg/d.

A look to the future includes missions to Mars. With current propulsion technologies, such missions would last ∼2.5 years, including a 6-mo transit time from Earth to Mars, an 18-mo Mars surface mission, and a 6-mo transit time for return to Earth. Prepackaged food will be used for the transit portions due to the lack of gravity during flight, which complicates food production and processing. A combination of prepackaged food and some methods for growing foods may be used during a surface stay. Therefore, much research is needed for establishment of nutritional standards and a safe and palatable food system (1,2,9).

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