Nutritional Concerns of Spaceflight

Scott M. Smith
NASA Johnson Space Center
Houston, TX 77058

Barbara L. Rice
Enterprise Advisory Services, Inc.
Houston, TX 77058

Introduction

Nutrition has played a critical role throughout the history of exploration, and space exploration is no exception. While a one- to two-week flight aboard the Space Shuttle might be analogous to a camping trip, adequate nutrition is absolutely critical while spending several months on the International Space Station (Figure 1) or several years on a mission to another planet. To ensure adequate nutrition, space nutrition specialists must know how much of the individual nutrients astronauts need, and these nutrients must be available in the spaceflight food system. To complicate matters, these spaceflight nutritional requirements are influenced by many of the physiological changes that occur during spaceflight. In this chapter, we describe some of these changes, their impact on crew health, and ways NASA is investigating how to minimize these changes. We also review the space food systems, issues involved in setting up a cafeteria in a weightless environment, and information about dietary intake of nutrients during space missions.

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Space Physiology

Spacecraft, the space environment, and weightlessness itself all impact human physiology. Clean air, drinkable water, and effective waste collection systems are required for maintaining a habitable environment. Without the atmosphere to protect them, astronauts are exposed to a much higher level of radiation than individuals on the Earth. Weightlessness impacts almost every system in the body, including those of the bones, muscles, heart and blood vessels, and nerves, just to name a few. We review here some primary systems affected in weightlessness that have particular relevance for nutrition: the skeletal, muscular, and hematological systems.

Bone

Bone loss, especially in the legs, is significant during spaceflight. This is most important on flights longer than 30 days, because the amount of bone lost increases as the length of time in space increases. Weightlessness also increases excretion of calcium in the urine and the risk of forming kidney (renal) stones. Both of these conditions are related to bone loss. Experiments done in space have shown that about 200 to 250 milligrams of calcium are lost from the bone each day.

Many nutrients are important for healthy bone. Calcium and vitamin D are very important for bone health. When a food containing calcium is eaten, the calcium is absorbed by the intestines and goes into the bloodstream. Absorption of calcium from the intestines decreases during spaceflight. Even when astronauts take extra calcium as a supplement, they still lose bone. The decreased absorption of calcium in space is one reason calcium supplements do not correct the bone loss.

On Earth, the body can produce vitamin D after the skin is exposed to the sun's ultraviolet light. In space, astronauts could receive too much ultraviolet light, so spacecraft are shielded to prevent this exposure. Because of this, all of the astronauts' vitamin D has to be provided by their diet. However, it is very common for vitamin D levels to decrease during spaceflight.

Sodium intake is also a concern during spaceflight, because space diets tend to have relatively high amounts of sodium. Increased dietary sodium is associated with increased amounts of calcium in the urine, and may relate to the increased renal stone risk of spaceflight. The potential effect of these and other nutrients on the maintenance of bone health during spaceflight highlight the importance of optimal dietary intake.

Bone is a living tissue, and is constantly being remodeled. This remodeling is achieved through breakdown of existing bone tissue (a process called resorption) and formation of new bone tissue. Chemicals in the blood and urine can be measured to tell us about the relative amounts of bone resorption and formation. During spaceflight, bone resorption increases significantly, and formation either remains unchanged or decreases slightly. The net effect of this imbalance is a loss of bone mass.

Scientists still have many questions about spaceflight bone loss. Some very important questions are "Is the lost bone fully replaced after flight?" and "Is the quality (or strength) of the replaced bone the same as the bone that was there before flight?" Preliminary data seem to show that some crew members do indeed regain their preflight bone mass after they return, but this process takes about two or three times as long as their flight. The ability to understand and counteract weightlessness-induced bone loss remains a critical issue for astronaut health and safety during and after long exploration missions.

The changes in bone during spaceflight are very similar to those seen in certain situations on the ground. There are similarities to osteoporosis, and even paralysis. While osteoporosis has many causes, the end result seems to be similar to spaceflight bone loss. Paralyzed individuals have biochemical changes very similar to those of astronauts. This is because in both cases the bones are not being used for support as they are in ambulatory people. In fact, one of the ways spaceflight bone loss is studied is to have people lie in bed for several weeks. Using this approach, scientists attempt to understand the mechanisms of bone loss and to test ways to counteract it. If they can find ways to successfully counteract spaceflight bone loss, doctors may be able to use similar methods to treat people with osteoporosis or paralysis.

Muscle

Loss of body weight (mass) is a consistent finding throughout the history of spaceflight, on both short- and long-term flights. Typically these losses are small (1 to 5% of body mass), but they can reach ten to fifteen percent of preflight body mass. Although a 1% body weight loss can be explained by loss of body water, most of the observed loss of body weight is accounted for by loss of muscle and adipose (fat) tissue. Weightlessness leads to loss of muscle mass and muscle volume and weakens muscle performance, especially in the legs. The loss is believed to be related to a metabolic stress associated with spaceflight. These findings are similar to those found in patients with serious diseases or trauma, such as burn patients.

Exercise routines have not succeeded in maintaining muscle mass or strength of astronauts during spaceflight. Most of the exercises performed have been aerobic (e.g., treadmill, bicycle). Use of resistive exercise has been proposed to aid in the maintenance of both muscle and bone during flight. This is exercise in which a weight (or another person) provides resistance to exercise against. Ground-based studies (not done in space) of resistive exercise show that it may be helpful, not only for muscle but also for bone. Studies being conducted on the International Space Station are testing the effectiveness of this exercise for astronauts.

Blood

A decrease in the mass of red blood cells (i.e., the total amount of blood in the body) is a consistent finding after short- and long-term spaceflight. The actual composition of the blood changes little because the amount of fluid (blood plasma) decreases as well. The net result is that the total volume of blood in the circulatory system decreases. While this loss is significant (about 10 to 15% below preflight levels), it seems to be simply an adaptation to spaceflight with no reported effect on body function during flight.

The initial loss of red blood cells seems to happen because newly synthesized cells (which are not needed in a smaller blood volume) are destroyed, until a new steady state is reached. One consequence of the increased destruction of red blood cells is that the iron released when they are destroyed is processed for storage in the body. Too much iron may be harmful, and thus is a concern for long space missions.

Space Food Systems

Historically, space food systems have evolved as the U.S. space programs have developed. The early Mercury program (from 1961 through 1963) included food packaged in bite-sized cubes, freeze-dried powders, and semi-liquid foods such as ham salad stuffed into aluminum tubes.

The Gemini program (from 1965 through 1966) continued using bite-sized cubes, which were coated with plain gelatin to reduce crumbs that might clog the air-handling system. The freeze-dried foods were put into a special plastic container to make rehydrating easier. Gemini astronauts were able to select their own menu items.

The Apollo program (from 1968 through 1972) was the first to have hot water. This made rehydrating foods easier, and improved taste and quality. Apollo astronauts were the first crew members to use utensils with the "spoonbowl," which was developed to eliminate having to consume food into the mouth directly from the package.

The quality, taste, and variety of foods improved even more during the Skylab program (from 1973 through 1974), the only program to have refrigerators and freezers for storage of fresh foods. The menu contained seventy-two different food items. Skylab also had a dining area with a table and footholds to help the astronauts stay in place while eating.

The Shuttle program, which began in 1981, includes food prepared here on Earth from grocery store shelves (Figures 2 and 3). With the help of a dietitian, crew members plan individual three-meal-per-day menus that contain a balanced supply of the nutrients needed or recommended for living and working in space. Crew members are allowed to add a few of their own personal favorite foods, which may require special packaging to withstand the rigors of spaceflight. Each crew member's food is identified with a color dot placed on each package. Extra foods are available for snacks from a pantry supply. The freeze-dried foods are rehydrated using water that is generated by the Shuttle's fuel cells. Each crew member has his or her own meal tray and assembles the meal by attaching food packages to Velcro™ dots on the tray. The foods are eaten right from the package, or if desired they may be heated in a convection oven in the Shuttle galley.

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During the Shuttle-Mir program (from 1995 through 1998) a joint menu was used that contained half Russian and half U.S. Shuttle foods. These had to meet the nutritional needs established by technical committees representing both space programs. The Russian four-meal-per-day menu was used, with each space program providing two of the meals. Three larger meals were designed to be eaten as scheduled meals; the fourth meal was composed of foods that could be eaten at any time throughout the day and was similar to the Shuttle pantry food items.

The current food system for the International Space Station, which started in 2000, is similar to the system used in the Shuttle-Mir Program. The four-meal-per-day menu plan is used, with equal provision of foods by the U.S. and Russian space programs. The menu is composed mainly of packaged foods that are freeze-dried and thermostabilized (canned), with very few fresh foods. The crew members plan their own menus with the assistance of the dietitian, and an effort is made to include all of the nutrients needed for working in the space environment. After the habitation module galley is equipped with refrigerators, freezers, and a microwave-convection oven, a more extensive menu including a variety of fresh foods will be available.

Dietary Intake During Spaceflight

Dietary intake has been monitored on select Apollo, Skylab, Shuttle, and Shuttle-Mir flights as a part of scientific studies. Preflight and postflight intakes are collected using conventional methods for dietary assessment. Crew members are provided a diet record logbook and digital scale, or the foods are weighed by the research dietitian and provided during each of the five- to eighteen-day data collection sessions. A variety of nutrient analysis software programs are used. Crew members record their intake during spaceflight by writing it in a log or, more frequently, using a barcode reader (Figure 4) that scans the food package label and then they record the amount consumed. The amounts of certain nutrients in each meal are calculated from the record of how much of each type of food was eaten, plus knowledge of the amount of each nutrient in each type of food. Nutrient calculations using chemical analysis data for each spaceflight food item are performed after the flight when the food record logs are returned. On the International Space Station, crew members complete a food frequency questionnaire each week and the data is down linked for analysis. Dietary intake can thus be assessed in real time. Changes in diet may then be suggested to the crew members to prevent nutrient deficiencies on these long-term flights of 90 to 360 days.

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A primary concern with the dietary intake during flight is that astronauts consume enough energy or calories for optimal work performance and good health. Of the flight crews that have been monitored, only the Skylab crew members consumed enough energy: ninety-nine percent of their predicted intake. Most of the crew members in other flight programs consumed about seventy percent of what was planned. On the Skylab flights, much time and attention was given to eating and food preparation, and the crew members' extensive exercise program may have stimulated their appetite. On all other flights, the crew members have had a very busy schedule, with little time and attention devoted to eating.

Crew members' dietary intakes on Skylab, Shuttle, and Shuttle-Mir flights have tended to be higher in carbohydrate and lower in fat than their preflight intakes. This change may have been related to an abundance of foods high in carbohydrates, especially sugar-sweetened beverages, or perhaps these items may be more easily prepared during a busy work schedule. Ample fat sources are available in the Shuttle food inventory; more than half of the main dish items contain greater than thirty percent of their calories as fat.

Intake of fluid should be about 2000 milliliters (2 liters) per day, which is sufficient to prevent dehydration and kidney stone formation. Fluid intakes have varied from one thousand to four thousand milliliters per day, indicating that some crew members are getting less than the recommended amount.

Inflight sodium intakes of all crew members have exceeded the recommendation of less than 3500 milligrams per day. Sodium intake is high because many of the "off-the-shelf" food items used have a high sodium content.

Calcium intakes of all crew members have been below the recommended range of one thousand to twelve hundred milligrams per day. This level is estimated to minimize the bone mineral loss that occurs during spaceflight.

Iron intakes have been fifty to sixty percent greater than the recommendation of ten milligrams per day. As with sodium, iron intakes are high because the food items have already been iron-fortified. Too much iron in the body may cause tissue damage.

Summary

Nutrition is critical for health, both on Earth and during spaceflight. These are some of the specific nutrition concerns for spaceflight:

Adequate consumption of calories for energy.

Adequate fluid intake to prevent dehydration and renal stones.

Adequate calcium to minimize bone loss.

There seems to be an excess of both sodium and iron in the inflight diet compared to predicted requirements. A food delivery system needs to be designed to include foods that will provide nutrients at the recommended levels, while providing variety and palatability to make eating more pleasant.

The International Space Station represents the beginning of an era of humans living and working in space, with the potential for a permanent human presence in space. Nutrition will play a vital role in ensuring the health and safety of spacefaring individuals, whether they are in low Earth orbit or on journeys to the moon, Mars, or beyond. While we have answered some important basic questions, we have only begun to understand the impact of weightlessness on the human body. A more complete understanding will not only help enable humans to explore our universe, but will provide information needed to maintain human health and treat diseases here on Earth.

Selected Readings

Bourland, Charles T. (1998). "Advances in Food Systems for Space Flight." *Life Support & Biosphere Science* 5:71-77.

Lane, Helen W., and Smith, Scott M. (1998). "Nutrition in Space." In *Modern Nutrition in Health and Disease,* 9th edition, eds. M. E. Shils, J. A. Olson, M. Shike, and A. C. Ross. Baltimore: Williams & Wilkins, pp. 783-788.

Smith, Scott M.; Davis-Street, Janis E.; Rice, Barbara L.; Nillen, Jeannie L; Gillman, Patricia L.; and Block, Gladys. (2001). "Nutritional Status Assessment in Semi-Closed Environments: Ground-Based and Space Flight Studies in Humans." *Journal of Nutrition* 131:2053-2061.

Smith, Scott M., and Lane, Helen W. (1999). "Gravity and Space Flight: Effects on Nutritional Status." *Current Opinion in Clinical Nutrition and Metabolic Care* 2:335-338.

Smith, Scott M., and Lane, Helen W. "Nutritional Support." In *Principles of Clinical Medicine for Space Flight,* eds. Michael R. Barratt and Sam L. Pool. New York: Springer-Verlag (*in press*, 2002).

Figure Legends

Figure 1. The International Space Station (ISS) as seen from a departing Space Shuttle. This photo, taken in 2001, shows the ISS in an early phase of construction. The initial elements were launched to orbit in 1998, with the first ISS crew entering the space station in 2000. Crews of three rotate every three to four months.

Figure 2. Space Shuttle meal tray. A typical meal, beverage and utensils are shown here, including scissors to open the packages. Velcro™ holds the food packages, while magnets keep the utensils from flying away. Color dots (green) identify for which crewmember the utensils are intended.

Figure 3. Types of Shuttle foods.

Figure 4. Astronaut Rhea Seddon enters information in the barcode reader (she is also holding the food item in her left hand). This photo, taken inside the Shuttle middeck, also shows astronaut David Wolf enjoying his meal in the background.