

CHANGES IN NUTRITIONAL ISSUES OVER THE LAST 45 YEARS

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BODY WEIGHT CHANGES, FOOD INTAKE, AND ENERGY UTILIZATION

Energy utilization and food intake¹⁻⁴, were measured in many of the U.S. space programs. Throughout these various space missions, food intake has been estimated using either food records or food frequency questionnaires¹⁻⁴. Energy utilization research used a variety of methods including indirect calorimetry method of doubly labeled water^{2,3}. These results demonstrated that energy utilization levels could be predicted using the World Health Organization (WHO) calculations using moderate activity. Results show that astronauts, except for those on Skylab space station in the 1970s, had daily in-flight food intakes below those calculated necessary to meet energy needs. As a result, body weight loss has been common in astronauts (**Fig.1**). During 2000-2004 on the early International Space Station (ISS) missions (128- to 185-d durations), 11 astronauts had slight reductions in lean body mass from 56.2 ± 7.2 to 55.1 ± 8.3 kg and fat mass from 15.3 ± 3.6 to 14.7 ± 3.4 kg, with body weight changes between 5 and 10% of preflight body weight⁴. Generally astronauts lose lean body mass as well as fat mass during space flight; this is most likely related to negative energy balance and weight loss. NASA provides foods that provide energy at levels equivalent to the WHO calculation using moderate activity levels.

The ISS medical care program instituted a weekly measurement of food consumption using a specially designed space food frequency questionnaire. The questionnaire was validated through ground-based studies with foods similar to those supplied to the ISS crew members⁵. Food frequency questionnaires are a good method of estimating food intake when the number of food items is limited and a closed inventory system is used, as on the ISS. If a crew member has inadequate energy consumption, the medical doctor is notified, and recommendations are made to improve intake. This system has improved the food intakes of crew members on the ISS.

It is not clear why energy utilization is similar between Earth and space activities, especially in microgravity as the astronaut is not walking against a gravitational force. On Earth, it would appear that there is more energy required to walk compared to floating in space. Yet, energy utilization measured by a variety of methods demonstrates that energy needs in space flight are the same as on Earth^{2,3}. Although the exercise is not similar to Earth, the astronauts do move and use their limbs to move around. There is also some indication that basal energy utilization is greater in space flight, and endocrine changes (such as increased cortisol levels) may increase metabolic rates⁶. Interestingly, the energy consumption measured during the lunar extravehicular activities (EVAs) was lower than energy utilization in underwater – neutral buoyancy – training⁶.

MUSCULOSKELETAL CHANGES

Space flight has a significant negative impact on the musculoskeletal system. Losses of muscle volume and strength are routinely reported⁷⁻⁹. For instance, after only 15 days in flight, astronauts had an 8% loss of hamstring volume, a 6% loss of quadriceps volume,

and a loss of over 10% in the intrinsic lumbar region muscles. Various exercises are used to decrease muscle losses, including a set of resistance exercises⁹. Resistance exercise with adequate food intake may prevent loss of muscle function (and bone mass) during space flight¹⁰. It is assumed that these levels of exercise will be needed to maintain fitness for long-duration space flight.

Even during the best nutritional conditions, on Skylab missions, with very little loss of body weight, the astronauts were in negative nitrogen balance¹¹. These astronauts routinely completed heavy aerobic exercises. Although consumption of hypocaloric diets decreases protein syntheses, it is not the only mechanism for loss of muscle mass. One protein turnover study with astronauts on the Russian space station, Mir, showed increased protein turnover¹². Ground based studies with simulated microgravity – bed rest - indicate that there may be a decrease in protein synthesis in the presence of adequate caloric intake^{13,14}. To complicate muscle metabolism studies even further, there are endocrine changes such as increased insulin insensitivity and increased blood cortisol levels. Exercise, especially with resistance protocols, has ameliorated some of these changes. During tours on the ISS, astronauts participate in aerobic and resistance exercises at a level that maintains aerobic capacity and muscle strength. Some research indicates that a high protein diet, especially high in essential amino acids, will improve protein synthesis for maintaining muscle mass and function^{2,3}. In these studies, bed rest subjects had increased protein synthesis and reduced muscle and strength loss with an essential amino acid supplement. These researchers suggest that the combination of exercise and an amino acid supplement will prevent the increases in protein turnover and

maintain muscle functions. However, this protocol of amino acid supplementation increased bone resorption markers that indicate increased bone losses^{15, 16}.

In contrast to the muscle countermeasures, no methods have been proven to prevent bone loss during space flight^{16, 17}. All astronauts on long-duration missions lose bone mineral density in at least one region (such as spine, hip, or femoral neck), but subject-to-subject variability in response to flight is large¹⁸. Recent research showed that loss of trabecular (spongy) bone was greater than loss of cortical bone (the outer layer of compact bone)¹⁹. This is an important observation for the development of methods designed to prevent bone loss during flight, as well as the development of rehabilitation protocols after space flight.

The astronauts on the Skylab missions, who had adequate food and exercise, also had increased excretion of bone resorption markers throughout their missions²⁰. Pre- and postflight assessments of ISS astronauts indicated that their bone resorption markers remained elevated on landing day⁴. Smith et al.²¹ used stable isotopes to study calcium homeostasis of 6 long-duration Mir crew members. Their results suggest that around 250 mg of calcium is lost from bone per day during flight, and that while this loss was reversed after landing, it was so great that it would take about 2-3 times the duration of the mission to regain the lost calcium. Ground-based studies suggest that dietary factors, including dietary sodium intake and the ratio of animal protein intake to potassium in the diet, may affect bone health²².

Nutrition plays an important role in bone health in space flight as well as on Earth. Due to the lack of sunlight, the synthesis of vitamin D decreases during space flight. The 3 crew members who flew on Skylab for 84 d had lower serum concentrations of 25-hydroxyvitamin D during flight than before flight¹¹. Crew members who flew long-duration missions on the Russian Space Station Mir for 115 to 195 days had similar decreases^{21, 23}. Compared with preflight concentrations, their parathyroid hormone also decreased during flight and increased after flight⁵. Markers of bone resorption (such as urinary N-telopeptide and pyridinium crosslinks) significantly increased during and after flight^{4, 20}.

An important objective of ongoing research is to develop exercise, pharmacological, and dietary treatments to prevent losses in musculoskeletal function. In addition, centrifugation as a source of “artificial gravity” is being tested on subjects undergoing bed rest to help determine if the 1/6 gravity of the Moon will be beneficial to muscle or bone. Another prevention strategy is use of lower body negative pressure (LBNP) in conjunction with treadmill exercise with bed rest subjects. Bed rest mimics the lack of gravitational force and the LBNP mimics gravity’s pull. In microgravity the gravity that pulls body fluids toward the feet is very weak. In a bed rest study with multiple sets of identical twins, bone resorption markers significantly decreased in the twins who received the LBNP/exercise treatment²⁴.

RADIATION AND NUTRITION

A major hazard of space travel is radiation exposure. For regulatory purposes, astronauts are considered radiation workers. An individual living at a high altitude (as in Denver)

will have 200 times less radiation exposure than an astronaut in space. Moon radiation includes both galactic cosmic rays and solar particle events (sun flares)²⁵. Radiation exposure on the Moon is more dangerous than on the Shuttle or ISS, where the Earth's atmosphere provides some protection. Radiation exposure of astronauts during spacewalks (extravehicular activity, or EVA) is also a concern²⁵ because the space suit offers minimal protection.

Radiation can cause chromosome and DNA damage, including single- and double-strand breaks, deletion of nitrogenous bases, and rupture of hydrogen bonds^{26,27}. Studies show that single-strand DNA breaks can be repaired or rejoined; therefore, maintaining proper DNA repair will be an important mechanism for preventing cell destruction and DNA mutation leading to cancer. Also, ionizing radiation interacts with cell components to produce free radicals. Because of radiation exposure, astronauts are at greater risk of having cataracts, altered central nervous system function, and changes in bone stem cell production. Radiation exposure in general can increase the incidence of cancers, skin cancer in particular, and can affect fertility.

One marker of oxidative damage to DNA is 8-hydroxydeoxyguanosine (8(OH)dG), excretions of which was significantly increased after long-duration space flight⁵. A marker for increased peroxidation is superoxide dismutase (SOD), an intermediate enzyme in the metabolism of free radical ions in water. In the same study⁴, SOD was lower on landing day than before flight.

Food components such as antioxidants or even dietary-plant-fiber may prevent and/or ameliorate radiation damage. Antioxidants and some plant fibers may be protective.

Numerous animal studies with ionizing radiation suggest that food antioxidants can prevent some of the radiation-induced damage. The next step is to determine the ability of these dietary compounds to mitigate space radiation risks.

SUMMARY

The prospect of a lunar outpost to conduct science and learn how to live and work off the Earth is exciting. The nutritional sciences will focus on the issues of overall health, with emphasis on skeletal muscle health and prevention of radiation damage. There is a great deal of research needed to determine the nutritional and food component potential for preventing the changes that occur in space flight. Further research is also needed on the interactions of systems and countermeasures, such as protein-amino acid needs for enhancement of muscle protein synthesis while not being detrimental for bone health. The interrelationship between radiation exposure, nutrition, and food components has just begun.

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FIGURE LEGENDS

Figure 1. Postflight weight loss in astronauts on Shuttle, Skylab, Mir, and ISS flights. Data are expressed as percent change in body weight at landing compared to preflight.

