

# Nutrition issues for space exploration

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## **Abstract**

Optimal nutrition will be critical for crew members who embark on space exploration missions. Nutritional assessment provides an opportunity to ensure that crew members begin their missions in optimal nutritional status, to document changes in status during a mission, and to assess changes after landing to facilitate return of the crew to their normal status as soon as possible after landing. Nutritional assessment provides the basis for intervention, if it is necessary, to maintain optimal status throughout the mission. We report here our nutritional assessment of the US astronauts who participated in the first twelve International Space Station missions.

Keywords: Nutrition; International Space Station; Nutritional assessment; Vitamin D; Oxidative damage; Energy intake

## **1. Background**

The limited data pertaining to nutritional alterations during spaceflight suggest that the nutritional status of astronauts is compromised during and after flight. Inadequate dietary intake and weight loss are often considered hallmarks of spaceflight. Low energy intake has been observed since the Apollo missions, where the average energy intake was  $64 \pm 14\%$  of the amount recommended [1]. Some crews on the International Space Station

(ISS), however, have maintained intake at 85-95% of predicted requirements, indicating that energy intake can be maintained on orbit [2]. Consistent with the low energy intake during flight, the average body weight of crew members was lower after landing than before flight. Crew members who consumed adequate energy maintained their body weight. The low energy intake and weight loss may explain some, but likely not all, of the changes in nutrient status observed after 4–6 months of spaceflight.

After ISS flights, the first 11 U.S. crew members had decreased hematocrit, ferritin saturation, and serum iron and transferrin concentrations, and serum ferritin was increased ( $P < 0.05$ ) [2]. The finding that acute-phase proteins other than ferritin are generally unchanged after flight suggests that the changes in iron metabolism are unlikely to be solely a result of an inflammatory response. Urinary 8-hydroxy-2'-deoxyguanosine concentration is greater and red blood cell superoxide dismutase is less after long-duration spaceflight ( $P < 0.05$ ), indicating increased oxidative damage.

Bone loss during spaceflight remains one of the most critical challenges to astronaut health on space exploration missions. An increase in bone resorption of ISS crew members after flight was indicated by several markers. Vitamin D status also remains a challenge for long-duration space travelers, who lack ultraviolet light exposure in the shielded craft.

These data provide evidence that bone loss, compromised vitamin status, and oxidative damage are the most important nutritional concerns for space travelers. Other nutrient issues exist, including concerns about the stability of nutrients in the food system, which are exposed to long-term storage and radiation during flight. Defining nutrient requirements and being able to provide and maintain those nutrients on exploration missions will be crucial for maintaining crew member health.

## **2. Methods**

Nutritional assessment data from the first 11 U.S. ISS crew members have been published [2]. In this report, we have included all U.S. crew members through Expedition 12.

### *2.1. Subjects*

Subjects were crew members on ISS Expeditions 1-12 (missions of 128 to 195 days during 2000-2006). The age of the 15 subjects (1 or 2 subjects per Expedition, 2 female) was  $46.6 \pm 5.1$  y (mean  $\pm$  SD) before flight. For all but 2 of the crew members, preflight sample collections were conducted at the Johnson Space Center in Houston, Texas. For 5 of the Expeditions ( $n = 7$ ), postflight biological samples were collected at the Kennedy Space Center in Florida, and those for the other 3 Expeditions ( $n = 8$ ) were collected in Star City, Russia. Regardless of collection site, all samples were analyzed at the Johnson

Space Center. The protocol for this study was approved by the Johnson Space Center Committee for the Protection of Human Subjects.

## *2.2. Food system*

The ISS food system provides a menu with a cycle of 6 to 10 days. About half of the food items are supplied by the United States and the other half are supplied by Russia [3]. Foods are packaged in single-serving containers, and are intermediate moisture foods, or are in natural form, or are thermostabilized, dehydrated, or irradiated [3]. Before each mission, menus are planned to fulfill defined nutritional requirements that have been derived from spaceflight research, extrapolated from speculation about the effects of spaceflight on nutrient needs, or applied directly from ground-based Dietary Reference Intakes for micronutrients and WHO recommendations [4]. A key concern for spaceflight, and a limitation of the food system, is providing adequate amounts of vitamin D. Accordingly, vitamin D supplements (400 IU per day) were provided for the crew members.

## *2.3 Food Frequency Questionnaire (FFQ)*

During flight, crew members were asked to record their dietary intake once per week using an FFQ designed for use with the spaceflight food system. This FFQ has been validated in a ground-based model of long-duration spaceflight [5]. Given the closed food system (with repetitive menu cycle), known portion sizes, and precise nutrient content for each food item in the system, the FFQ designed for spaceflight is much more reliable than a standard food questionnaire.

A unique FFQ was developed for each Expedition to the International Space Station, and was based on the specific menu for the crew on board, and foods potentially on board from earlier crews. Nutrient analyses by the NASA Johnson Space Center Water and Food Analytical Laboratory were used to categorize foods in the FFQ to optimize data from the nutrients of interest.

#### *2.4 Biological sample collection and processing*

Preflight blood and initial urine samples from all crew members were collected at about 180 days before launch (L-180) and L-45. For crew members landing in the US, postflight samples were collected on landing day (R+0) within 2 to 4 hours of landing. For crew members on the Expeditions that landed in Russia, postflight urine collection began on R+1 or R+2, and blood samples were collected 9 to 16 hours after landing. Preflight blood samples were collected after an 8-h fast, but fasting did not always occur before collection of postflight blood samples. Crew members on the 5 Shuttle landings in the U.S. generally fasted 4 to 6 hours before the R+0 blood collection.

Blood samples were collected into appropriate tubes and processed to yield whole blood, plasma, or serum, depending on the specific analyte to be measured. A total of about 23.7 mL of blood was collected from each subject for all tests described here.

Pre- and postflight urine samples were collected over 48 hours in individual bottles and stored in coolers until they were processed. Twenty-four-hour urine pools were created, pH was measured, and aliquots were prepared and frozen at -70 °C until analysis.

## 2.5 Biochemical analyses

Regardless of sample collection site, analyses were performed at the Johnson Space Center by trained personnel. Most analyses were performed by standard commercial techniques, as described previously [2, 5, 6].

## 2.6 Statistical analysis

Statistical analyses were designed to test the hypothesis that postflight nutritional status was different from preflight nutritional status. Statistical analyses were performed with the data in their original form.

Preflight mean values were determined and compared with postflight (R+0 through R+2) data using a 1-way repeated-measures ANOVA, with time as the repeated factor. The dependent variables were the analytes measured. *Post hoc* Bonferroni tests were performed to assess specific differences between sampling times.

Statistical analyses were performed using SigmaStat software 3.01a (SPSS, Chicago, IL, USA), and  $P < 0.05$  was the level of significance. Data are expressed as mean  $\pm$  SD.

## 3. Results

The average energy intake of the 15 U.S. ISS crew members was  $74 \pm 11\%$  of the WHO recommendation. Energy intake among U.S. ISS crew members has been increasing in recent years compared to the intake of the crews on the first four 4- to 6-month expeditions ( $70.8 \pm 10.8\%$  for expeditions 1-4, and  $75.6 \pm 11.4\%$  for expeditions 5-12).

The reason for concern about chronic inadequate energy intake is that weight loss could occur over an extended period, along with possible accelerated muscle and bone loss. Consistent with inadequate energy intake, body weight was significantly lower after 4-6 months of spaceflight than it was before flight ( $P < 0.01$ ) (**Fig. 1**).

It is well documented that iron metabolism is altered during spaceflight [7, 8]. In 14 U.S. ISS crew members, when postflight values were compared with preflight values, serum ferritin increased 34% ( $P < 0.001$ ), the percent saturation of ferritin decreased 27% ( $P < 0.05$ ), and transferrin and hematocrit decreased approximately 11 and 5%, respectively ( $P < 0.001$ ). Transferrin receptors and ferritin iron were unchanged.

Other striking changes associated with long-duration spaceflight included changes in vitamin and mineral status. For example, red blood cell (RBC) folate was consistently decreased about 22% after flight in long-duration crew members ( $P < 0.001$ ,  $n = 15$ ). It is not known whether folate status would continue to decrease during longer missions; therefore, it is important that the mechanism be investigated further. The likely cause of the decrease in RBC folate is that crew members were not taking in the recommended amounts of folate during flight; however, the possibility that folate is not stable in the space food system or folate metabolism changes during flight cannot be ignored. Other changes included consistent decreases in urinary magnesium and phosphorus ( $P < 0.001$ ). Urinary magnesium decreased 37% while phosphorus decreased 40%.

Evidence exists that oxidative stress occurs after long-duration spaceflight. Superoxide dismutase, an antioxidant enzyme that functions as a scavenger of superoxide radicals, decreased 13% ( $P < 0.05$ ,  $n = 15$ ). Urinary 8-hydroxy-2'-deoxyguanosine, a marker of

oxidative damage to DNA, was 22% greater after flight than before flight ( $P < 0.05$ ,  $n = 13$ ), slightly lower than the increase that we previously reported for the first 11 U.S. ISS crew members.

After flight, plasma phylloquinone was 47% less than before flight. This was a greater decrease than what we previously reported for the first 11 U.S. crew members. Vitamin D status was also consistently decreased among crew members despite supplementation during flight. In 14 U.S. ISS crew members, 25-hydroxyvitamin D was 27% less after flight than before flight ( $n = 15$ ,  $P < 0.001$ ).

Similar to what was reported for the first 11 U.S. ISS crew members, all markers of bone resorption that were measured were significantly greater after landing than before launch. The excretion of deoxypyridinoline was 77% greater ( $P < 0.001$ ), excretion of N-telopeptide was about 39% greater ( $P < 0.001$ ), and excretion of pyridinium crosslinks was 72% greater ( $P < 0.001$ ) after landing than before launch.

#### **4. Discussion**

Good nutrition is critical for human health, and this is true for those on Earth and those traveling in space. Adequate nutrient intake is especially important for space travelers because of the length of time crew members are exposed to a limited, mostly closed, food system. Many concerns exist, including energy intake, macronutrient balance, vitamin and mineral deficiencies or excesses, and environmental factors.

Energy intake is a significant concern, as crew members throughout the history of space travel have tended to consume fewer calories than required. Skylab and some ISS crew members have maintained energy intake and body mass, proving that this is not impossible. Not only does maintaining energy intake provide calories, but energy intake is correlated with intake of other nutrients, and thus if insufficient energy is consumed, then other nutrients are at risk of insufficiency as well.

Vitamin D continues to be a concern for space travelers, despite the provision of vitamin D supplements. An ongoing debate within the field of nutrition highlights the fact that existing normal ranges (deficiency at  $< 25$  nmol 25-hydroxyvitamin D/L) are too low. Using parathyroid hormone (PTH) suppression as an index, along with disease incidence data, many have suggested that 80 nmol/L should be normal. In fact, when preflight vitamin D and PTH data were evaluated, even though the number of subjects evaluated was small, these two indices appear negatively correlated as expected (**Fig. 2**).

The reported nutritional assessment findings before and after flight are compelling, but they provide only a pre- and postflight evaluation. NASA has recently undertaken to extend this protocol – to include additional markers of nutritional status, to include a session approximately 30 days after flight, and most notably to collect inflight blood and urine samples. This expanded protocol will commence with Expedition 14, and will enable a much better understanding of the impact of spaceflight on nutrition.

In addition to biochemical assessments of nutritional status, the other issue to be investigated pertains to the stability of the food itself. It has not been determined whether the radiation environment of space has an impact on nutrient content of foods. While the

radiation dose itself might not be expected to have a direct impact on nutrients, the potential for radiation to initiate oxidative damage in the foods is very high, especially given the duration of exposure for many of these foods. A study was initiated in July 2006 to investigate this further, and to document the stability of nutrients in foods flown to the ISS. Results of this study will provide critical information for the design and development of vehicles and food systems for exploration missions.

Early explorers found out the importance of nutrition, often at their peril. As we seek to explore beyond the planet, nutrition is even more critical, as no food will be found along the way. Understanding nutrition requirements for space travelers and ensuring that the food system contains these nutrients in adequate amounts, that no deficiencies or excesses exist, and that the nutrients are stable throughout the duration of the flight, are but a few of the critical issues. The food system must contain these nutrients – and must contain foods that are palatable and of sufficient variety to mitigate negative crew responses. It will be important to optimize nutrient intake to mitigate the negative effects of spaceflight on the body, while also ensuring that nutrition does not have a negative impact on other countermeasures, and that those same countermeasures do not have a negative impact on nutritional status. It will not be easy to ensure that all of these aspects of nutrition, and more, are accounted for, but all will be required for mission success.

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## Figures

Figure 1. Body weight loss of astronauts in several space programs. Each data point represents an individual crew member's body weight loss at landing expressed as a percentage of preflight weight.

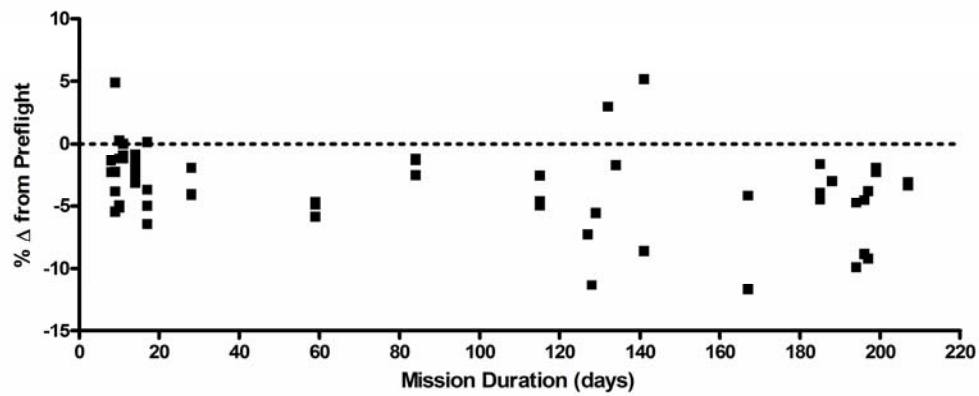


Figure 2. Serum vitamin D and parathyroid hormone (PTH) concentrations before flight in ISS astronauts.

