High-Sodium Diets in Spaceflight: Health Consequences and Methods to Reduce Intake

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For some 50 years, the dietitians, researchers, and food scientists of the National Aeronautics and Space Administration (NASA) have provided the nutritional and food safety standards, developed the food systems, and produced the food provisions for all U.S. human spaceflights. In the past 12 years, the challenge to provide food has become more pronounced with the continuous operation of the International Space Station (ISS).[1,2] All diets must meet the health and safety guidelines for crewmembers living and working in space for up to 6 months.[3,4] NASA researchers spent about 20 years studying the effects of dietary sodium on the health and safety of crewmembers, resulting in the conclusion that the dietary sodium content should be lowered.

The ISS standard menu utilized in 2010 contained more than 5,600 mg/day of sodium and 2,900 kcal/day. Dietary sodium intake averaged about 4,600 mg/day over the first 18 ISS expeditions (an expedition is an ISS increment that has a set of crewmembers and generally lasts 6 months). At the same time, energy intake was generally less than 2,500 kcal/day.[1]

Historically, NASA research focused on two aspects of sodium: fluid and electrolytes, and bone. Initially, there was concern about fluid and electrolyte changes due to microgravity. Investigators studied endocrine controls along with measurements of fluid spaces (intracellular, extracellular, and total body water) and electrolyte levels in urine and blood. Although extracellular fluid levels decreased during space flight, total body water did not. Urine volumes decreased and concentration increased, but blood sodium levels did not change during flight. Urinary sodium levels reflected dietary sodium intakes (e.g. increased dietary sodium = increased urinary sodium). The endocrine hormones, such as aldosterone, antidiuretic hormone, and angiotensin systems, reflected normal regulation of blood sodium levels. Thus, the level of sodium in the astronauts' foods was not considered an issue related to the fluid changes in space flight.

At the same time, NASA and the European Space Agency[5] investigators conducted calcium and bone studies, using actual space flight and simulations of microgravity with bed rest. As dietary sodium levels increased, urinary sodium and calcium levels increased. A major concern for many years was that the combination of the concentrated urine, with higher concentrations of calcium and purines due to bone and muscle losses, respectively, would increase the risk factors for renal stones.

As crew members flew longer flights during the ISS program, vision changes were noted in some crew members.[5] The medical team attributed this to the increased intracranial pressures found after spaceflight. With these changes, NASA developed some countermeasures including lowering the sodium levels in the foods. This required a major reformulation effort described below.

U.S. Food System for the ISS

The current U.S. food system for the ISS is based on the Space Shuttle food system that has been in use since the beginning of the Space Shuttle program in 1981. Because of the longer duration of the ISS missions, the ISS food system was expanded from the more limited Space Shuttle food list to a current inventory of about 200 foods and beverages. A standard menu of foods for an 8-day rotation is packed pantry style (i.e., all meats are packed together, all vegetables are packed together, etc.). Crewmembers assemble meals from the various food categories, so they are eating from a standard menu but not eating in the exact meal combinations on the menu. In addition, crewmembers are allowed a small quantity of bonus food items to augment the standard menu. This bonus food equates to about 10% of the food supply available to a crewmember in orbit and can consist of more U.S. space food or even some commercial shelf-stable food items.

The NASA food system menus are high in sodium because only ambient-stored processed foods are used. The lack of refrigerators and freezers for food, both on the Space Shuttles and the ISS, mandates a shelf-stable food system. Shelf-stable foods historically tend to be high in sodium because sodium aids in the preservation of these foods.[1] Furthermore, the Space Shuttle food system was designed with the premise of using as many commercial off-the-shelf (COTS) foods as possible to save money. The NASA food systems that preceded Space Shuttle consisted of custom-produced foods that were extremely costly. The use of COTS foods automatically led to a high level of sodium in the diet because commercially processed foods tend to be high in sodium, which is an inexpensive way to make foods taste good. In addition, crews in spaceflight have very limited, if any, access to fresh fruits and vegetables, which are naturally low in sodium. With so few fresh foods available to astronauts, the sodium content of the diet is increased even further over the typical ground-based diet.

The Process to Reduce Dietary Sodium

In March 2010, the Space Food Systems Laboratory (SFSL) at NASA's Johnson Space Center began a project to reformulate existing products to reduce sodium levels. The project team in the SFSL consisted of several food scientists and a dietitian. This team reviewed the sodium content of the some 200 different foods and beverages on NASA's food list and identified 90 different thermostabilized and rehydratable food products to be reformulated. These 90 were selected on the basis of sodium content.

The team developed a schedule for reformulation that would have required about 4 years to complete with in-house resources. NASA management wanted the project completed in less time, so to augment the SFSL reformulation efforts, two outside firms, one with expertise in freeze-dried foods and one with expertise in thermostabilized foods, were hired to expedite the project. The 90 products were reformulated in about 2 years, with 30 foods each for the two consultant firms and for the SFSL. Existing foods were reformulated, rather than replaced with totally different products because the existing food list was balanced among food types, providing variety that is important to ISS crewmembers during their lengthy stays in orbit.

The primary approach was to remove sodium by either using low-sodium versions of ingredients or by removing salt altogether and using other ingredients, such as spices and herbs, to compensate for the sodium in the reformulated products. Some of the spices included were disodium inosinate and disodium guanylate to increase the umami flavor in savory foods along with lemon juice, basil, oregano, sugar, Mrs. Dash Fiesta Lime Seasoning®, and Mrs. Dash Garlic & Herb Seasoning®.

Because of the low volumes of food required for spaceflight, NASA has an advantage over the commercial food industry in being able to use these typically much more expensive ingredients in formulations without significant economic impact. For freeze-dried food products, NASA had, in many instances, used COTS frozen foods and further processed them into freeze-dried foods. The reformulation of these products produced foods made from individual ingredients rather than further processed commercial products with the expected increased labor costs. In contrast, NASA's thermostabilized products were already predominately made from individual ingredients, so this project had little effect on labor costs to produce these items.

When a new formulation was identified for a product, a small test batch was made in the SFSL for evaluation by the project team. This often resulted in rejection and rework of many of the formulations. When the team found a new, acceptable formulation, the next step was to produce enough of the product to allow for large-scale sensory evaluation using a group of untrained volunteer panelists. These evaluations were publicized to the astronaut corps and some participation by current astronauts did occur.

During sensory evaluation, the product was rated for appearance, color, odor, flavor, and texture, and given an overall rating. A 9-point hedonic scale was used for these rankings, and an overall score of 6.0 or higher was required before the product was deemed acceptable for further production. Occasionally a reformulated product did not pass this evaluation. In that case, the comments made by the panelists were evaluated and revisions were made to the formulation and tested again. In the case of the reformulations done by the two consultant companies, those reformulations went directly to large-scale sensory evaluation.

Sensory evaluations of the final reduced-sodium formulations showed acceptance scores that were not significantly lower than the scores of their higher-sodium predecessors and in a few cases were higher. The net result of the reformulation task was a 40% reduction in the sodium content of the previous ISS standard menu from 5,600 mg/day to approximately 3300 mg/day.

These reduced-sodium products were manufactured and shipped (launched) to the ISS. The orbiting crews began consuming significant quantities of these reformulated foods in 2013 and the project team is anxiously awaiting their feedback.

It is interesting to note that salt, in liquid form, has always been available for crewmembers to use in orbit. One of the assumptions of this project was that liquid salt would continue to be made available to the crewmembers. NASA decided that the reduced-sodium diet would not be mandated to all crewmembers, but reduced-sodium products would be available for crewmembers who desired them or had symptoms of increased intracranial pressure. As another variable, Russian foods as well as foods provided by the Canadian, European, and Japanese space agencies are available on the ISS— and NASA obviously cannot regulate the sodium content of those foods.

Measuring Dietary Intakes: Food Frequency Questionnaire

With the advent of the ISS, nutrition researchers needed an easy-to-use valid method to determine dietary intakes. This led to testing a food frequency questionnaire (FFQ) originally developed by Gladys Block. The questionnaire was validated against 24-hour dietary records during studies of crewmembers who lived in a closed chamber for 60 or 91 days.[7, 8]

This semi-quantitative FFQ is self-administered each week.[4] The FFQ is designed to include the foods that are available for a specific expedition and requires about 5 to 10 minutes to complete. The FFQ assesses intake of seven nutrients including sodium along with energy, protein, potassium, iron, fluids, and calcium. Data from the completed questionnaire are routinely provided to the medical-nutrition teams for assessments of the astronauts' diets. These teams then make recommendations to the astronauts about their diets within 48 hours of completion of the FFQ, thereby allowing for self-corrections in their diets. With a sodium recommendation of 3,500 mg/day, the sodium reformulation project will enable astronauts to meet this level.

Summary

The level of sodium in astronauts' diets has always been high and, in light of the continuous operation of the ISS, NASA decided to reduce astronauts' dietary sodium intake. Within a couple of years, NASA hopes that astronauts will consume diets closer to 3,500 mg/day, and if they consume only items from the U.S. menu, they will easily meet this recommendation.

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