To Boldly Go Where No Food has Gone Before

It's the final frontier of nutritional research, offering unlimited challenges in an environment with the most unknowns. And even though the world has long since determined that its moon is not made of cheese, the question of what to eat while outside Earth's atmosphere is as central to the topic of space travel as how one should get there in the first place.

For over 20 years, Barbara L. Rice, MA, RD, LD, has worked to answer that question as a research dietitian at the National Aeronautics and Space Administration's (NASA's) Johnson Space Center in Houston, TX. Participants at the American Dietetic Association's 2010 Food & Nutrition Conference & Expo got a taste of that research as part of her presentation there titled "Nutrition Research in Space and Its Down to Earth Applications."

But early in the month of August, Rice was busy preparing for NASA's Expedition 25 which would carry astronauts into an extended mission just the next month. In addition to her research on the effects of microgravity on nutritional needs, Rice plans the menus for certain research studies as well as dietary reporting systems astronauts use while in orbit.

When asked, just for fun, what one food she'd want to make certain was with her in case she was stranded on a deserted space station, the registered dietitian (RD) in her came out as she answered, "I really don't know. The balance is really important. It's a fact you can't just eat one or two things. One doesn't do it on Earth and one wouldn't do it if they were stranded up on a deserted space station."

Given the enclosed spacecraft environment including weightlessness, far from the lush green vegetables popping up out of the ground, the need to achieve nutritional variety poses a complex challenge. As with much of the space program's efforts, the research generated to solve these riddles offers a wealth of applications for the Earth-bound human.

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SYMBIOTIC EVOLUTION

Scientists have been studying the impact space flight has on the body since humans first flew into space in the early 1960s. In addition to a loss of bone mineral and lean muscle mass, spaceflight may prompt changes in iron metabolism. And as Rice explained, studying diet is one way NASA can combat these impediments to space travel. As the agency seeks to lengthen the time astronauts spend in space—with perhaps the ultimate goal being long-term habitation on other planets—the impact of weightlessness and isolated environments is only magnified.

On the whole, "exposure to microgravity is known to affect many physiological systems. Body fluids shift from the lower extremities toward the torso and head, bone mineral and lean body mass are lost, and red blood cell mass declines . . . . Another area in which nutrition poses a concern is inadequate intake with crew members often consume 70-80% of predicted energy requirement. Significant losses of fluid and electrolytes during the first few days of flight, as well as depressed appetite, may result and/or interfere with physiological adaptation to microgravity" (1).

A brief summary of America's human space flight program begins in 1961 with the Mercury launches, the flight lengths of which ranged from 15 minutes to 34 hours (2). The Gemini flights between 1965 and 1966 lasted 5 hours to 14 days. Each generation of space flight advancements lengthened the time in microgravity, as participants in the Skylab Space Station between 1973 and 1974 spent up to 84 days in orbit. Today, astronauts aboard the International Space Station (ISS) might be in space as many as 6 months.

Between 2000 and 2004, studies on astronauts aboard the ISS found reductions between 5% and 10% of their preflight weight (2). Research has shown that after only 15 days in flight, astronauts could lose up to 8% of their hamstring volume, 6% of their quadriceps volume, and more than 10% of the intrinsic lumbar region muscles (2).

In a NASA-funded study led by biologists at Marquette University (Milwaukee, WI), researchers found that not only the muscle fibers of astronauts' calves decreased, but the power generated by those muscles was reduced as well (3). Those affects were reversible through exercise once back on Earth.

But bone mineral loss has shown to be at least as, if not more, problematic than the loss of muscle mass. "In contrast to the muscle countermeasures, interventions tried, to date, have helped but not completely prevented bone loss during spaceflight. Virtually 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 large" (2).

Studies of members aboard the Russian Mir station suggest that about 250 mg calcium is lost daily from bone during flight. This loss was reversed after landing, but it could take two to three times longer than the mission to regain the calcium (2).

In addition to the impact of microgravity, the issue of radiation plays a role in astronauts' health and dietary needs. From a regulatory standpoint, astronauts are considered radiation workers due to the lack of atmospheric protection in space (2). This radiation can result in both chromosomal and DNA damage, both single- and double-strand breaks, deletion of nitrogenous bases, and the rupture of hydrogen bonds. Mutations of this nature can produce free radicals and, ultimately, forms of cancer, cataracts, and altered central nervous system function (2).

"One marker of oxidative damage to DNA is 8-hydroxydeoxyguanosine, excretions of which were significantly increased after long-duration spaceflight. A marker for increased peroxidation is superoxide dismutase, an intermediate enzyme in the metabolism of free radical ions in water. In the same study, superoxide dismutase was lower on landing day than before flight" (2). Therefore, foods that serve as antioxidants, n-3 fatty acids, and dietary plant fiber are required to help offset this damage (2).

And just as rocket technology has evolved in 45 years of spaceflight, so has nutritional delivery methods. The early Mercury, Gemini, and Apollo missions provided a good deal of food in the form of squeezable tubes (2). Bite-sized units minimized the formation of crumbs, but these early programs did not include methods to heat foods. Some Apollo flights in the early 1970s had heated water available in the command module but not the lunar module. It wasn't until the Skylab Space Station that refrigerators and freezers were provided for astronauts in space. The space Shuttle and ISS food systems have gone back to relying on shelf-stable foods, but many improvements have been made over the years.

Today, Rice and her team work with astronauts well in advance of their flights. Each astronaut has a customized menu and diet plan, as well as the education and information to use it accordingly.

"That's correct," Rice said when asked whether proper nutrition can effectively lengthen an astronaut's productivity in space, and thus allow for longer trips. For instance, due to concerns stemming from calcium loss, astronauts are asked to drink at least 2 L of liquid per day to prevent renal stones. To date, renal stones have largely been avoided, she said. "We send them up with good information and good food and plans for exercise."

In recent years, astronauts who have followed the ever-advancing guidelines have been able to minimize the amount of bone and muscle loss experienced in space, she said. "And they want to do well. They're high achievers."

Rice said each astronaut is given a listing of foods from which they can choose during a scheduled tasting session. Portions and quantities are determined by bodyweight and personal factors. An example of a typical space flight menu includes a breakfast consisting of thermostabilized blueberry or raspberry yogurt, rehydratable granola with blueberries, orange drink and coffee with cream and sugar (2). That day's lunch could be irradiated beef fajitas, fresh tortillas, irradiated applesauce, almonds, and lemonade. Dinner might be rehydratable shrimp cocktail, thermostabilized grilled chicken, rehydratable macaroni and cheese, rehydratable green beans and mushrooms, candy-coated chocolates, lemonade, and tea with lemon and sugar (2).

Rice explained that Russian resupply vehicles bring fresh foods up to the ISS periodically. These include oranges, lemons, apples, cabbage, tangerines, onions, and tomatoes. ISS menu cycles have increased from 6 to 16 days in the last decade, and NASA food scientists have developed more than 65 new foods for those menus (2).

Anecdotal evidence has also demonstrated an impact on the taste buds of individuals in space. Whether this stems from stress or microgravity, is physiological or psychological, Rice said scientists aren't sure. But it's one of the reasons spicy foods are popular among the astronauts.

"They like shrimp cocktail a lot," she said, noting the astronauts' requests to zip up the flavoring of foods they would normally like plain on Earth. "So that's been a challenge for the food research and development team."

Communication is extensive between the two groups. Each week the astronauts complete a food frequency questionnaire, reporting back to NASA how much of what they ate each week. Those data are sent to their physicians and matched up with other health diagnostics.

"So we do have a way of checking whether they're eating," Rice laughed, quick to point out the astronauts don't require too much looking after. The physical and mental requirements to become and stay an astronaut tend to weed out those who disregard their health. Still, the mental and physical strains of spaceflight are tough on even the best of candidates. "It's a wonderful adventure, but it doesn't have the comforts of home," she said.

Oddly enough, research has shown that energy utilization levels can be predicted using the World Health Organization calculations for moderate activity, meaning astronauts burn as many calories in a weightless environment as they do on Earth (2).

Rice said research is still ongoing as to the question of why astronauts in a weightless environment with limited activity would burn the same amount of calories as they do on Earth, but several ideas come to mind. Astronauts exercise extensively, especially on ISS missions. Whether the energy cost of this exercise is different than on Earth is not known.

"There is also some indication that basal energy utilization is increased during spaceflight, and endocrine changes (such as increased cortisol levels) may increase metabolic rates" (2). Complimentary research has shown that energy consumption during lunar extravehicular activities was lower than in underwater training with neutral buoyancy (2).

REWARDING CAREER OPPORTUNITIES IN NUTRITION

For anyone with an interest in science, NASA represents a dream come true. Rice has been with the agency since 1990, following an eclectic career spanning the field of nutrition.

Earning her undergraduate degree in dietetics from the University of Kentucky in 1962, she added a master's degree in nutrition and foods from California State University in Los Angeles in 1974. Prior to NASA, her career took her from schools, universities, and hospitals in California to the University of Texas system, as well as her own private nutritional consulting practice.

"I've been fortunate to work in a time when there were a lot of opportunities," she said.

Working within the institutional setting of hospitals and schools, she said the one-on-one relationship with patients was not only enjoyable, but good background training for what she does now. Helping motivate people to change their lives through diet is very rewarding, whether working with children or full-grown astronauts. Establishing her own practice was also good experience, she said.

"The private practice was very exciting because I built it from the ground up, from just one client," she said.

But NASA, she said, represents the final frontier in nutrition.

"It was exciting to get a chance to work with that research," she said of coming aboard the agency when work on the longer space flights was just emerging. Working with astronauts is phenomenal, considering the stellar conditioning and aptitudes of the people involved.

And NASA has opportunities for RDs, even those still early in their career, Rice said. The agency offers a number of highly competitive internships for college students, as well as individuals preparing to take their final examinations. These programs range from 1-day job shadowing to 1- and 2-month internships.

"We always ask them what it is they'd like to learn, because there's no need in them coming and just twiddling their thumbs," she said. Grant money may also be available to work on spaceflight technology at the university level, she said, adding that's something students have to apply for through their schools. But coordinating research with a professor is good experience for a job at NASA, as research is integral to the program. Rice described the position she currently holds as a master's degree level job requiring a minimum of 5 years experience. That experience, she said, needs to include a strong foundation in nutrition, as well as counseling and research.

APPLICATIONS HERE AT HOME

Studies conducted in the NASA program have numerous applications on Earth. Rice pointed out that unlike many of the clinical studies, the research obtained from working with astronauts starts out with incredibly healthy individuals. Astronauts start from a point of peak nutrition and fitness, and then work themselves into environments of high stress before returning to a state of normalcy. Studies on Earth typically revolve around individuals with existing and often co-existing health problems which may confound interpretations of the results.

Under the banner of "tools and methods," space technology that might soon be coming to a laboratory nearby includes the "saliva test." While researchers use all available fluids to study nutritional impact, from blood and urine to fecal matter, ongoing work has yielded better testing on saliva that produces similar data. Both children and elderly populations would appreciate a world free of blood draws and the needles that perform them, Rice said.

More specifically yet, the negative effects brought about by weightlessness seem to mimic those associated with old age, she said. From the loss of bone density and health, to a reduction in muscle mass and red blood cells, the use of food to combat these problems, instead of pills, is applicable to all concerned.

Rice spoke excitedly about work being done by her colleagues in the "Pro-K" study, which focuses on the idea that dietary intake can predict and protect against changes in bone metabolism during spaceflight.

“We’ve come a long ways in 20 years for nutrition to have a study like that,” she said, describing it as the first potential countermeasure to bone loss based wholly on food intake instead of pills or exercise.

According to NASA’s Web site, the experiment, which is based out of Johnson Space Center under the direction of principal investigator Scott M. Smith, PhD, tests the hypothesis that a diet with a decreased ratio of animal protein to potassium will lead to decreased loss of bone mineral during flight. The specific goal for the study is to test this hypothesis by determining whether the ratio of acid (animal protein) to base (potassium) precursors in the diet is correlated with bone metabolism during flight and bone loss after space flight. The hope is that the experiment will yield a countermeasure for bone loss that lacks side effects and requires no additional materials or flight cost.

“Given the growing trend in the United States toward diets high in animal protein, the proposed research also has direct public health significance” (4).

Also of interest are the similarities between the effects of microgravity and those of extended bed rest. Another ongoing study conducted on the ISS is the SOLO project, which stands for Sodium Loading in Microgravity. This project, led by principal investigator Martina Heer, PhD, of the University of Bonn in Germany, studies fluid and salt retention in the body during space flight (5).

According to the study’s data sheet, microgravity leads to an activation of sodium retaining hormones, even at normal sodium levels. This is believed to cause positive sodium balances, while high and even average sodium intake in microgravity exacerbates the rise in bone resorption. The study is metabolically controlled and is a continuation of research in the study of salt retention during bed rest and space flights.

Rice also described the Advanced Life Systems department of NASA, the mission of which is to design ways to generate food on other planets.

“In whatever direction we might go,” she said, humans will need food. But how far humans go will dictate the types of food and systems of delivery needed to accompany them. Rice explained that trips to the moon take a matter of months. A trip to Mars could require humans to be gone for 2 to 3 years. All of the stresses caused by spaceflight would be present, if not magnified by the extended period of time. Meanwhile, new foods and new methods of growing food would be required. “Any program, wherever we go, if you’re gone for 2 to 3 years, you’ll need a special food system to meet the nutritional needs.”

Rice said the sodium and iron content of food on Earth has been a particular concern with astronauts due to physiological concerns or changes experienced in microgravity. “And that’s being worked on,” she said. But like any RD on Earth will say, taste has to be considered. Salt-free nuts and lower-sodium entrees are projects underway, both of which have taste at the forefront of concerns. “We buy much of the food off the shelf which tends to be high in sodium and fortified with iron which is not needed in spaceflight,” she added.

The difficulty, perhaps even implausibility, of raising meat animals in outer space also leads one to believe that plants will provide the bulk of nutrition in extended missions.

“It’s one thing to grow it,” she said of experiments on lettuce, peanuts, and soybeans in microgravity environments. “But it’s another thing to get it in a manner that humans can consume it.”

This challenge opens up opportunities into mobile food processing and packaging technologies, she said, explaining “that can be applied to other hungry populations on Earth.”

The need to generate food with high nutritional quality, in limited space, with limited money and resources, can obviously be useful with respect to Earth, considering the number of malnourished cultures here. And the answers to solving those problems might someday come from work on another world.

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