

NUTRITION

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INTRODUCTION

Nutritional investigators have two primary goals. The first is to determine the nutritional requirements to support optimal performance and health during space flight. The second is to develop food systems for space flight. This includes both launched and off-Earth-grown sustainable food systems.

A diet that is deficient in one or more essential nutrients will compromise the success of a space mission. The history of explorations of Earth contains many examples of nutrient deficiencies leading to poor physical performance, deficiency disease and, in the worst case, death. The severity and time course of decrements in performance differ with respect to the nutrient, but history clearly proves that good nutrition is a vital consideration for human endeavors, particularly one as major as the exploration of space. Not surprisingly, three of the Tier I priorities identified during the critical path assessment of bioastronautics are nutritionally related. As such nutrition research is vital to the future of human space flight.

Nutrient balance studies performed during the Skylab missions demonstrated that, with few exceptions, the absorption of macronutrients and many micronutrients have similar fractional absorptions as on Earth at 1G. As such, the United States Recommended Dietary Allowances have been taken as a baseline for nutritional requirements during space flight and exploration. This baseline has served as a starting point from which to identify an optimal diet for astronauts.

Nutritional scientists at the January 2001 Bioastronautics Workshop meeting in Galveston, TX identified six critical questions for future research in order to support optimal performance of astronauts during space flight and exploration.

The most important as yet unanswered question is why astronauts regulate their energy intake at a level insufficient to maintain body energy stores and mass. Previous studies have determined the energy requirements for space flight, yet the average astronaut will consume 500 to 1000kcal/d less energy than required. This leads to weight loss and accelerates muscle atrophy and bone loss. The cause of, and countermeasures for, this dysregulation are unknown.

Protein requirements for muscle maintenance are not yet fully known. While it is clear that providing protein intake in excess of that on Earth will not ameliorate the problem of muscle atrophy, it is known that other countermeasures such as exercise or pharmacologic countermeasures will not be effective in the absence of sufficient protein intake.

Refining the calcium and other nutrient requirements for bone health is even more critical. Like protein, it is known that increased calcium intake will not ameliorate the problem of bone loss in microgravity. Moreover, any excess calcium intake will increase the risk for renal stone formation, while insufficient intake negates the protective effects of any countermeasures aimed at preventing bone loss. Calcium requirements must, therefore, be carefully matched to the countermeasures employed in space flight.

Some micronutrient requirements are expected to be higher in microgravity than the current baseline requirements at 1G. For example, increased intakes of antioxidants are known to reduce radiation damage to cells within the human body in ground-based studies and thus it is anticipated that antioxidant requirements in space flight will be higher than at 1G because of increased concern with radiation exposure

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in space. Evidence presented at this meeting also suggests that micronutrients other than calcium may be effective countermeasures for bone loss in microgravity, but the requirements as well as the mechanism(s) remain unknown.

Great strides have been made recently toward the development of flexible food systems that are to be launched from Earth for astronaut support. Advances have also been made in the area of biomass production. The latter is critical for development of a sustainable system for space exploration, one of the six major nutrition research problems that remain to be solved.

The sixth future research question identified by participants of this workshop is to determine how storage and preparation of the foods in the food systems under development will alter the bioavailability of nutrients. Both degradation and nutrient-nutrient interactions can reduce nutrient bioavailability and cause nutrient deficiencies.

These issues of nutritional requirements for astronauts during space flight and exploration are vital questions that require further research.

SUMMARY OF PRESENTATIONS

Two animal model studies of body mass regulation were reported. Both investigated the role of leptin in energy homeostasis. Dr. Horwitz exposed rats to 2G forces for 8 weeks. After an initial period of reduced food intake and weight loss (compared to 1G controls), rats with a functional leptin system recovered their 1G rates of food intake and growth. In contrast, rats with a genetically abnormal leptin receptor failed to compensate with increased food intake and did not grow during the 2G exposure indicating that a fully functional leptin regulatory pathway is required for acclimation to altered gravity. In a related study, Ms. Warren and coworkers measured plasma leptin levels in rats on the day after they returned from a 16-day space flight. Unlike humans, the rats had a greater (+16%) food intake in microgravity than did the 1G controls; they did, however, lose weight indicating, as in humans, an inability to regulate energy stores. The expectation for leptin measured on the day after return to 1G was for a lower level, secondary to weight loss and to what is typically a day of low food intake. Plasma leptin levels, however, were greatly elevated (160% greater) compared to ground-based controls. Although it is possible that this is a temporal effect of returning to 1G, the high levels may also indicate an alteration in the leptin regulatory pathway in microgravity. Further investigations of this regulatory system are warranted and may provide insight into the altered regulation of intake and body mass in humans exposed to space flight.

Only one investigation of protein requirements for sustaining muscle mass in microgravity was reported. Drs. Sheffield-Moore, Ferrando and coworkers tested the hypothesis that muscle atrophy observed in the microgravity of space flight may be due to the combined effects of unloading and stress-induced hypercortisolemia and the resulting hypotestosteronemia. Six healthy volunteers were made hypercortisolemic before and during 14 days of bed rest. Despite adequate nutrition, muscle breakdown was twice that of bed rest alone. Using epidermal burn patients as a model of stress, restoration of testosterone to high normal levels resulted in muscle protein being achieved with adequate nutrition, a response unattainable without testosterone. These results suggest restoration of microgravity-depressed testosterone levels to normal might maintain muscle mass during space flight. Dr. Stein is also conducting investigations into the alterations of muscle metabolism in microgravity. Although very preliminary at this time, use of gene-chip technology did identify some alteration in gene expression of genes involved in lipid and glucose oxidation. Data suggested a shift away from lipid oxidation and toward glucose oxidation in the muscle tissue of rats in microgravity. Further investigations are warranted as this may reflect a basic metabolic change associated with muscle wasting in microgravity.

Dr. Schoeller demonstrated that bioimpedance spectroscopy was valid under conditions of 6° head down tilt. This method of body composition assessment relies on only a small, light-weight instrument that could easily be used during space flight. The bioimpedance method tracked within individual fluid shifts. This study found changes as small as 2.6% of body composition could be detected within an individual. This technique should be useful for nutritional assessment during long-term space flight.

Microgravity-induced bone loss was addressed by several investigators. One of the more important findings related to calcium metabolism was reported by Dr. Smith and coworkers in the Bone/Muscle session. A dual stable isotope study was performed in astronauts during space flight. Results demonstrated the expected increase in bone breakdown and either no change or a reduction in bone synthesis. The absorption of oral calcium, however, was also reduced. This indicated that dietary calcium homeostasis was down-regulating intestinal absorption in response to unloading and that increased dietary calcium would not be a viable countermeasure for bone loss. Thus, countermeasure research for bone loss should be directed toward exercise and/or pharmacologic agents. When a safe, protective agent is identified, then optimal calcium intake for bone preservation without excessive urinary losses and risk of stone formation will need to be determined. With regard to countermeasures, a rather surprising finding related to bone was reported by Dr. Stoecker and coworkers. They found that the effect of vitamin E on bone strength in a hind limb animal model was dramatically altered during unloading. Animals from a hind limb suspension model that were given high dose vitamin E (500 µg) had higher bone strength in the unloaded bone than those given the requirement level of vitamin E (75 µg). The opposite result was observed at 1G, a finding that calls into the question the current assumption that vitamin requirements for microgravity are similar to those at 1G.

A second paper also suggested optimal health during space travel may be supported through increased nutrient requirements. The high radiation exposure in space flight raises concern about an increased risk of cancer. Dr. Lupton reported the results of animal model studies performed at 1G. Dr. Lupton and coworkers found increasing intakes of n-3 fatty acids from fish oils and pectin, a fermentable fiber, acted synergistically to reduce gastrointestinal cancer following radiation exposure.

In an unrelated study, Welage presented a novel model of intestinal absorption in microgravity. This model should prove very valuable for understanding the pharmacodynamics of drugs and possibly nutrient action, although there appears to be little effect of microgravity on nutrient absorption.

Three investigators presented data indicating major advances in the design of food systems for space exploration. Dr. Kokini demonstrated the feasibility of a novel extruder that was scaled down to a size that could be considered for potential use in space. Dr. Lee presented results that demonstrated the utility of extruder technology. The extruder could produce a wide variety of foods from a few components and thus provide for a varied diet, which can improve the quality of life during the long isolation associated with space exploration. Taken together, these two papers provided support for an ingredient-based food system for space flight. Such a system can reduce launch mass and increase nutrient shelf-life compared to pre-prepared foods. Dr. Hunter provided an abstract demonstrating success in designing a long-term diet from foods potentially available from a bioregenerative system combining launched ingredients with in-situ grown foods. A diet including 209 recipes passed taste testing and nutritional evaluation and thus demonstrated that a varied, palatable and nutritionally complete diet could be provided for long-term space travel.

It has been said that some astronauts pay little attention to the foods consumed during space flight, because they simply think of food as something to fuel their body and any fuel will do the job. This is a rather surprising statement from anyone in the aeronautics industry where fuel quality is paramount for successful flight. Admittedly, the human body does have greater flexibility with regard to fuel than a rocket engine, but with that flexibility come decrements in human performance. Current knowledge has provided a safe diet for astronauts living in microgravity for short periods of time; but the optimal diet is still unknown, particularly for long-term space habitation.