National Space Biomedical Research Institute
Science and Technology Program
Nutrition, Physical Fitness and Rehabilitation Team Strategic Plan
2007

Summary Description

Inadequate nutrition and fitness impact all aspects of long-duration spaceflight, from accelerating bone loss and reducing muscle function to diminished cognitive ability. Areas under investigation by the Nutrition, Physical Fitness and Rehabilitation Team are the quality and quantity of dietary intake and the type and quantity of exercise needed to reduce or eliminate muscle atrophy and bone loss. The Team also is addressing whether certain diets will help protect astronauts from cancer due to radiation exposure. Since nutrients are supplied by foods, the depressed food intake that often occurs during spaceflight is of particular concern. Also, current projects have shown that appropriate nutrition and exercise during spaceflight enhance the rehabilitation process after spaceflight. The benefits of using nutrition and exercise countermeasures in space have important applications on Earth. Sarcopenia (muscle wasting) is an important health problem particularly in elderly and bedridden individuals, and this can be ameliorated with appropriate diet and physical activity. The same diet intervention that is proposed to decrease the risk of radiation-enhanced colon cancer in space has also been shown to decrease the risk of chemical carcinogen-induced colon cancer on Earth.

Goals

Although every physiological system is positively affected by optimal nutrition and physical activity, at the current time the Team is focused on using nutrition and physical activity as countermeasures in three important risk areas as identified on the Bioastronautics Roadmap: 1) **Muscle** (risk #11 – reduced muscle mass, strength, and endurance; risk #12 – increased susceptibility to muscle damage); 2) **Carcinogenesis** (risk #28); and 3) **Bone** (risk #1 – accelerated bone loss and fracture risk). Optimizing nutrition and physical activity so that they can be used as effective countermeasures is the underlying goal addressed by this Team: **Nutrition** (risk #16- inadequate nutrition; risk #38 – maintain food quantity and quality) and **Physical Fitness** (risk #44 – mismatch between crew physical capabilities and task demands). In the future, as effective countermeasures are delivered to ameliorate loss of muscle mass and strength, radiation-enhanced cancer, and bone loss, and additional resources become available, the Team will expand its focus to include other identified risks. Next step priorities include using nutrition and physical activity to address risks involving psychosocial factors (risk #24) and immune dysfunction (risk #8). To summarize, the Nutrition, Physical Fitness and Rehabilitation Team currently has five goals. The two that are intrinsic to the Team are to #1 Optimize nutritional status and #2 Optimize physical fitness. These two goals provide the infrastructure for using nutrition and physical activity as countermeasures against loss of muscle mass and strength (Goal #3); radiation-enhanced carcinogenesis (Goal #4) and bone loss (Goal #5).

Objectives

Each of the overall goals, listed above, is addressed with a set of objectives, including anticipated deliverables and spin-offs for Earth.

Goal #1. Optimize nutritional status.

Objective #1. Assure that astronaut diets are adequate in all nutrients for the duration of each mission (stay on International Space Station [ISS]; sortie to the Moon; exploration mission to Mars).

Maintaining the potency of essential nutrients in foods flown on spacecraft is critical for crew health and safety. By definition, humans are not able to synthesize essential nutrients in the body and thus depend 100% on an adequate supply in the diet. It is well documented, on Earth, that food processing and long-term storage can diminish, and in some cases obliterate, nutrient efficacy. It is unknown what the effects are of current processing techniques used by NASA (thermostabilization, dehydration, and irradiation). The goal of our Team is to document nutrient potency of space foods as eaten in space, so that we can be assured that when astronaut diets are designed to deliver appropriate nutrients the nutrients are actually in the foods.

Objective #2. Develop an understanding of nutrient requirements in space that is sufficient to appropriately design diets to meet those nutrient requirements.

Nutrient requirements in space are not the same as those on Earth. Without knowledge of the differences in requirements in space vs. on Earth, it is impossible to design diets that meet nutritional needs for astronauts. Data pertaining to nutrient requirements in space are extremely limited. Despite this, several deficiencies/insufficiencies are consistently reported. These deficiencies include inadequate energy intake, depressed vitamin D, K and folate status, and diminished antioxidant capacity. The goal of our Team is to document nutrient requirements for spaceflight.

Objective #3. Decrease the gap between current astronaut energy intake and each astronaut's individual requirement for energy.

If astronauts do not eat the diets that have been designed to meet their nutrient requirements, they will be nutrient deficient. This is a very real problem since crew members on the ISS have been reported to consume a mean of 80% of their recommended energy intake, whereas reports from other missions show intakes around 60% of recommendations. Not only does depressed food intake result in specific nutrient deficiencies, lack of energy also puts an individual into a catabolic state. This means that a portion of ingested protein will be used for energy rather than protein synthesis and that muscle protein will break down to supply precursors for glucose (since control mechanisms are in place to keep glucose levels relatively stable). In addition, with the formation of ketone bodies, an acidic condition exists which can contribute to bone loss and kidney stone formation. The goal of our Team is to develop an integrated plan to help increase food/energy intake to a level that meets or exceeds nutritional requirements.

Anticipated deliverables. The deliverables to meet the goal of optimizing nutritional status are: 1) An interactive database on the nutrient content of astronaut food which will take into account the processing of that food; the storage time; and the effect of space radiation so that the true nutrient efficacy of each food will be known and available for diet planning; 2) A compendium of nutrient requirements for long-duration spaceflight. This document would be similar to the Dietary Reference Intakes of individuals on Earth and would be based on the peer-reviewed literature using an evidence-based review. Using the results from objectives #1 and #2 dietitians will be able to accurately plan astronaut diets in a mission-specific manner.

Earth Spin-offs. The process of developing an accurate and interactive database to use for formulating astronaut diets will require more attention to the effects of processing and long-term storage than typically considered for Earth diets. However, controlling for these factors (even though likely to be more significant than on Earth) will provide insight into how different the nutrient potency is as a function of processing and storage, so these factors can be considered for all diets. Importantly, there will be incentives to reformulate foods to optimize their nutritional content.

Goal #2. Optimize physical fitness.
Objective #1. Identify and develop effective countermeasures for maintaining/improving physical fitness during long-duration missions.

The first part of meeting this objective is to identify the approach to physical fitness that is most effective in protecting muscle, bone, and the cardiovascular system. Clearly, any given modality that is effective in protecting one system at the cost of the other systems is not optimal. Systems to investigate include the treadmill, ergometer, resistance training device, and artificial gravity. After the best approach is identified, critical studies need to be conducted examining the efficacy of specific devices such as the flywheel exercise device.

Objective #2. Contrast interval versus endurance training to optimize and minimize time required for training and the impact of these training paradigms on lactate appearance and removal.

With respect to muscle performance, the great majority of studies have focused on the two ends of the endurance spectrum (i.e. very short-duration activities requiring efforts lasting only a few seconds and activities lasting tens of minutes). As a consequence, we know very little about the ability of skeletal muscles to perform under conditions that require high-intensity activities that last for tens of seconds and where high productions of lactate occur. It is highly likely that there will come a time when astronauts have to perform under such conditions. In this context, studies should be performed that a) Contrast the effectiveness of interval versus continuous training; b) Examine lactate appearance and removal. Since interval training produces much higher lactate concentrations and this theoretically improves the removal of lactate, training approaches that incorporate interval training should be evaluated for their effectiveness in preserving muscle function.

Objective #3. Assure that space suit design appropriately considers factors contributing to physical fitness.

Studies should examine how the loss of physical fitness impacts performance while in an extravehicular activity (EVA) configuration. In the absence of resistance-training countermeasures, it seems reasonable to assume that missions of moderate to long duration will produce significant atrophy and loss of strength and endurance. Will these losses be compounded when wearing a spacesuit? This is an important issue that needs to be addressed to properly appreciate how the loss of physical fitness will impact overall functional capability. Hence, long-term bed-rest studies should be used in combination with spacesuit stress tests to identify:

- The individual and combined impacts on measures of physical fitness.
- The impact of wearing a spacesuit on lactate production in both a conditioned and deconditioned state.

Anticipated deliverables. Anticipated deliverables for this goal are an effective and validated countermeasure to protect/enhance physical fitness, together with testing on specific equipment and a protocol for using the equipment. In addition, there will be a contribution to design of the spacesuit taking physical fitness into consideration.

Earth Spin-offs. An exercise protocol to optimize physical fitness would be an important consideration to individuals confined to bed or limited in weight-bearing movement.

Goal #3. Develop an effective countermeasure against loss of muscle mass and strength.
Objective #1. Develop a nutritional supplement that will mitigate the negative effect of spaceflight on muscle mass and strength.

For muscle mass to be maintained, muscle protein synthesis must equal muscle protein degradation. Unfortunately, in space, degradation increases as a result of microgravity conditions, suboptimal nutritional status, and stress (e.g. elevated cortisol levels). At the same time, muscle protein synthesis is depressed. Our Team has already shown that the appropriate use of an essential amino acid supplement can mitigate the negative effect of spaceflight (using ground-based bed-rest studies as an analog) on loss of muscle mass by positively enhancing muscle protein synthesis. Optimizing this supplement and producing a product that tastes good and maintains its potency over time are planned next steps.

Objective #2. Develop an exercise protocol that will mitigate the negative effect of spaceflight on muscle mass and strength.

Our Team has also developed a resistance-training protocol that is effective in ameliorating the loss of muscle strength seen in a 28-day bed-rest study. However, this intervention was intensive (1 hour per day for 6 days per week). The next step is to test the protocol in several configurations to get the greatest effect with the least amount of astronaut time spent in exercise. See also objective #2 for Goal #2.

Objective #3. Develop a protocol for the timing of a supplement that promotes muscle protein synthesis to the exercise that supports muscle protein synthesis that maximizes the effectiveness of the two interventions.

There is a limited but consistent literature showing a highly synergistic effect of the timing of nutrient intake to exercise in enhancing muscle mass and strength. We have tested one such timed interval in a bed-rest study using an amino acid supplement together with a resistant-exercise protocol and found that timing indeed was important. Once the exercise component is optimized, it needs to be tested for appropriate timing with respect to nutrient intake.

Anticipated deliverables. The deliverable to counteract space-induced loss of muscle mass and strength will be an essential amino acid supplement plus an exercise protocol in an optimal, timed pattern between the two.

Earth Spin-offs. Muscle wasting as a consequence of bed rest due to aging, sickness or accident is a real problem on Earth and can benefit from an effective intervention.

Goal #4. Develop an effective countermeasure against radiation-enhanced colon cancer.

Objective #1. Develop a nutritional supplement that will decrease radiation-enhanced colon cancer.

Our Team has developed a supplement of omega 3 fatty acids plus a fermentable fiber which is effective at each stage of the tumorigenic process (initiation stage, promotion stage and final tumor development) in rats. The next stage is to transfer this protocol to humans by providing the supplements in a bed-rest study and measuring markers of inflammation (an enhancer of tumor development) together with markers of changes in colon gene expression patterns over time (determined by microarray analysis of exfoliated colonocytes isolated from fecal material). In addition to this existing research, we will pursue additional nutritional countermeasures to radiation-enhanced cancer.

Objective #2. Determine colon gene expression profiles at different time points in the tumorigenic process that can be used to predict and monitor the effect of radiation exposure, and diet over time.

Using the noninvasive technology described in Goal #4, objective #1, the plan is to develop gene expression profiles which can be used to monitor the effects of a chemical carcinogen, exposure to radiation, and also the efficacy of diet. Ultimately, the monitoring process will reveal changes that would signal the need for an intervention at a very early stage, before genetic changes occur.

Anticipated deliverables. The deliverables to protect against radiation-enhanced colon cancer will be a nutritional supplement in a form that astronauts will use and a noninvasive technology to track changes in colon gene expression profiles over time that can be used to both monitor and predict consequences of exposure to radiation and to diet.

Earth Spin-offs. Colon cancer is the second leading cause of death from cancer in the United States today, and it strikes men and women pretty equally. Diets designed to protect against the development of this disease are equally applicable on Earth. In particular, individuals getting radiation treatment for cancer or radiation workers have an increased risk of developing cancer from radiation. This protocol could be useful for them. The noninvasive technology for monitoring gene expression profiles over time is already in use in an NIH clinical trial and has the potential for identifying preneoplastic gene expression profiles where an early intervention (perhaps even a change of diet) could prevent the later development of colon cancer.

Goal #5. Develop an effective countermeasure against bone loss.

Objective #1. Develop an overall nutrition plan to optimize the factors protective of bone strength and minimize the negative factors that promote bone resorption.

Considerable data have been collected in the past several years on nutritional factors that impact bone in the bed-rest analog for space. These factors include the importance of calcium, appropriate energy intake, vitamin K and vitamin D to bone health. At the same time, there is a quite strong literature now on the negative effect of excess protein, and acidified metabolic pH and sodium intake on bone health. As a first step, we need an evidence-based review of all the peer-reviewed studies on diet and bone health and all of the NASA-archived data on the effect of diet on bone in space. Based on this review, together with the recent bed-rest studies done in the US and Europe, there may be sufficient data to recommend a nutritional protocol to protect bone health based on published data. Alternatively, if specific data are required to make such recommendations with a high level of comfort, then studies to fill these data gaps will be conducted.

Objective #2. Develop an overall physical activity plan to optimize bone strength.

Results from all bed-rest studies with physical activity protocols should also include measures of bone markers and optimally direct measurements on bone. Now that NASA has included bone measurements in its bed-rest protocol, we should be able within 3 – 5 years to make a conclusion as to the amount and type of exercise that is required to protect against bone loss.

Anticipated deliverables. Deliverables to meet the goal of developing an effective countermeasure against bone loss will include an evidence-based protocol for optimizing the nutrition content of space foods (and their selection for astronaut diets) to protect against bone loss. This will be reinforced by an optimized exercise protocol targeted to the same goal.

Earth Spin-offs. Osteoporosis and osteopenia are major public health problems in the United States today and could greatly benefit from improved protocols to protect against their development.

Strategies for Achieving Team Goals and Objectives

The primary strategies for achieving these goals are: 1) Partnering with NASA to achieve all goals and work as a Team to address them; 2) Exploiting the results of all peer-reviewed studies, and unpublished data from NASA as appropriate to make recommendations based on existing data; 3) Attracting the best scientists in the US to address high-priority risks by maintaining a transparent and fair grants program with NASA/NSBRI; 4) Cooperating/Collaborating with other teams within NSBRI to synchronize protocols as appropriate so that more than one countermeasure can be addressed simultaneously (or that one countermeasure can be measured for its effectiveness on multiple systems); 5) Including, where appropriate, an educational component for our customers – flight doctors and astronauts. An important part of the strategy for achieving the Team goals is to use established analogs for microgravity, isolation, space radiation and other critical issues pertinent to spaceflight. Such analogs include: bed rest, NEEMO, Devon Island, Desert Rats, Polar/Antarctic, the use of Brookhaven National Laboratory for radiation exposure, the use of the human centrifuge for artificial gravity experiments and the use of the hindlimb suspension model for animals.

Examples

One example of how these strategies work to meet a goal is evidenced by addressing Goal #1 Optimize Nutritional Status. We have already partnered with NASA/JSC to write the existing standards and to develop the gap needs and have agreed on the priorities. The primary people for Nutrition and Food at NASA/JSC and at NSBRI have worked together to develop methods for testing the nutrient content of space foods, and a preliminary project testing storage and radiation exposure is ongoing on ISS. Further long-term projects are planned. Scientists funded by NIH and other organizations have been attracted to this program, thus providing leveraging of additional resources, particularly for the understanding of mechanisms. Addressing the effect of diet and exercise has involved significant input and synergy projects with both the Muscle and Bone Teams at NSBRI. In each NSBRI-sponsored bed-rest study on a diet intervention, there have been "add on" projects for exercise and for measuring bone markers. Education programs have targeted the science behind the proposed countermeasures both at Grand Rounds for flight doctors, for streaming videos for general use, and in multiple national and international meetings to encourage cooperation/collaboration.

1-5 Year Timeframe. Within this timeframe, we will know the effect of processing and storage on the nutrients in space foods. We will have an educational program to stress the importance of meeting energy requirements in space to key performance factors. Within this timeframe, we should decide on the optimal overall exercise program to adopt for long-duration spaceflight, and the equipment to support that program. In addition, our input into spacesuit design should be considered. Goal #3 to protect against muscle wasting will have the knowledge base at the end of 4 years to reformulate a combined amino acid and omega 3 fatty acid supplement to enhance both muscle protein synthesis and protect against radiation-enhanced cancer (Goals 3 and 4). At the end of year 5, we will have the gene expression profiles that predict for later tumor development tested, verified and ready to apply to spaceflight.

6-10 Year Timeframe. We will have an interactive database for designing astronaut diets based on knowledge of nutrients in foods and nutrient needs as a function of space. Goal #1 will be met. During this time, the exercise protocols will be optimized. Goal #2 should be retired ~ year 8. Optimizing the exercise protocol will complete the nutrition/physical fitness countermeasure against muscle wasting and loss of muscle strength (Goal #3).