DIETARY IMPACTS ON ASTRONAUTS' BONES

Background

The primary goal of NASA's Nutritional Biochemistry Laboratory is to maintain astronaut health by determining the nutritional requirements for long-duration spaceflight. Using research from spaceflight and ground-based studies, researchers can develop, evaluate, and validate nutritional countermeasures (or preventions) to minimize the negative effects of long-duration spaceflight on the human body.

Figure 1: A scientist processing urine samples in the Nutritional Biochemistry Laboratory at NASA Johnson Space Center

The Nutritional Biochemistry Laboratory monitors the dietary intake and body mass of astronauts during their four to six-month-long missions on the International Space Station (ISS). In addition to general dietary intake issues, the metabolic properties of specific nutrients in spaceflight are also considered.

Researchers are exploring the amino acids in animal proteins and their effects on calcium metabolism. Excessive amounts of sulfur-containing amino acids (cysteine and methionine) can metabolize to create a slightly acidic environment in the body. Basic components of the diet, such as potassium salts—found in fruits and vegetables—can help neutralize these acid loads. Because bone itself is a large reservoir of calcium-containing base, an increase in acidity can affect calcium metabolism when there is not enough base in the diet. While this is just one factor which may contribute to the loss of bone mineral density in astronauts, it is a serious issue. Space exploration to destinations requiring more extended stays could be limited, unless effective countermeasures are established.

The benefits of using nutrition and altering dietary patterns as countermeasures include lowered risks for side effects, lowered costs, and minimal crew time required during flight. Research studies in other discipline areas (i.e., cardiovascular, muscle, bone, immunology, and radiation) have indicated nutrition as integral in determining successful countermeasures, and confirm that additional efforts in nutrition research are still needed.

However, countermeasures for maintaining astronaut health in space are not limited to nutrition and dietary plans alone. Exercise and medication are two other countermeasures that are often used to address various spaceflight-related health concerns. It is this multi-disciplinary approach that will be necessary to ultimately enable safer human exploration of space.

Problem

On Earth, human populations lose bone mass density at different rates. For example, the rate of bone loss for elderly men and women ranges from 1%–1.5% per year, whereas the rate of bone loss for an early postmenopausal woman could be as much as 2–3% per year.

Bone loss increases significantly when the human body is in a reduced gravity environment. Male and female astronauts on the International Space Station (ISS), or on future long-duration missions, can lose an average of 1–2% of their pre-flight bone mineral density *each month* they are in space, regardless of their age. This loss of bone calcium has been the focus of much research. While many factors seem to contribute to bone loss, a clear solution has not yet been determined. In this activity, you will analyze just one of the potential factors associated with bone loss.

A person's blood can become slightly acidic by consuming a diet high in animal protein and low in fruits and vegetables. Animal protein has a high level of amino acids. These amino acids contain sulfur which breaks down, forming sulfuric acid and influencing blood pH. Small decreases in blood pH make the blood more acidic and can activate the process of bone resorption (breakdown). To help neutralize this acid and slow the rate of bone resorption, calcium carbonate is mobilized.

Researchers at NASA recognize that there are many factors that affect the loss of calcium in bones. As you answer the following questions, assume that the amount of sulfuric acid in the blood is the only contributing factor.

A. Answer the following questions that relate to chemical reactions.

   I. Write a complete balanced equation for the reaction between sulfuric acid and calcium carbonate.

   II. Write the net ionic equation for the reaction.

B. While in space, the average astronaut loses approximately 200. mg of calcium carbonate per day. Assume all the calcium carbonate is used to neutralize the amount of sulfuric acid resulting from the breakdown of sulfur-containing amino acids.

   I. Determine the mass of sulfuric acid used in the process.

II. How much of this mass (in grams) is accounted for by the sulfur?

C. Carbonic acid, a by-product of the reaction between calcium carbonate and sulfuric acid, breaks down further to water and carbon dioxide. Based on the amount of calcium carbonate present:

I. What is the mass of carbon dioxide produced in the process?

II. Calculate the percentage of carbon dioxide attributed to bone loss? (Assume the average person exhales 1 kg of carbon dioxide per day.)

D. A visit to Mars may be on the forefront of space exploration. One of NASA's major concerns is the duration of time required for a Mars mission. Currently, astronauts spend an average of 6 months on an ISS mission. A trip to Mars, however, would require 9 months to arrive, 2–6 months to study the planet, and 9 months to return to Earth. It is currently projected that an astronaut would lose 1.50% of his or her pre-flight bone mineral density per month while on a Mars mission.

I. Assume that there are 1500 grams of calcium in an astronaut's bones pre-flight. Predict the mass of calcium that would remain after 1 year on a Mars mission.

II. Assume the astronaut referred to in part I had a bone loss rate on Earth of 0.450% before going into space. Predict the mass of calcium that would have remained in the astronaut's bones after the same 1-year period on Earth.

E. Based on the above information, how might astronauts' dietary decisions minimize their bone loss in space? Explain your reasoning.