MATH AND SCIENCE @ WORK

AP* BIOLOGY Student Edition

RENAL STONE RISK TO ASTRONAUTS

Background

Dietary factors can contribute to increased loss of bone mineral density and increased risk of developing renal stones, especially for astronauts during spaceflight.

To address these physiological risks in spaceflight, NASA's Nutritional Biochemistry Laboratory carefully monitors both the dietary intake and body mass of astronauts during their four to six-month-long missions on the International Space Station (ISS). Additionally, this laboratory studies the metabolic properties of specific nutrients in spaceflight.

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

From spaceflight and ground-based studies, researchers are able to develop, evaluate, and validate nutritional countermeasures (or preventions) to minimize these negative effects of long-duration spaceflight on the human body. For example, researchers are currently 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. The result can be an increase in bone demineralization.

Bone demineralization increases the risk of developing renal stones. Renal stones, popularly known as kidney stones, are small rock-like objects made from deposits of calcium and other minerals that form in the kidneys or urinary tract. Normally, calcium and protein, along with other minerals that build bone and muscle, are transferred to the bloodstream and then to the kidneys, where they are flushed out with bodily fluid. Without sufficient amounts of fluid, crystals can form and grow into stones. When stones block kidney drainage, they result in urinary obstruction and pain.

Renal stones can be extremely debilitating and, when they occur during spaceflight, can potentially end a mission. Medical therapy options that are widely available on Earth are severely limited during long-duration space exploration. Therefore, preventing renal stone formation is the most logical and cost-effective approach for spaceflight missions.

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 spaceflight. 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

In this problem, you will examine one of the adaptive effects of space travel on human physiology—a change in the chemical composition of urine that occurs both during spaceflight and after return to Earth. These biochemical changes in urine are known risk factors for the formation of renal stones.

Bone demineralization in microgravity environments results in increased blood levels of calcium and other minerals and proteins normally used for bone and muscle. These solutes travel through the bloodstream and are filtered by the kidneys, which results in increased calcium excretion in the urine. Without enough fluid to wash them away, crystals can form and develop into renal stones.

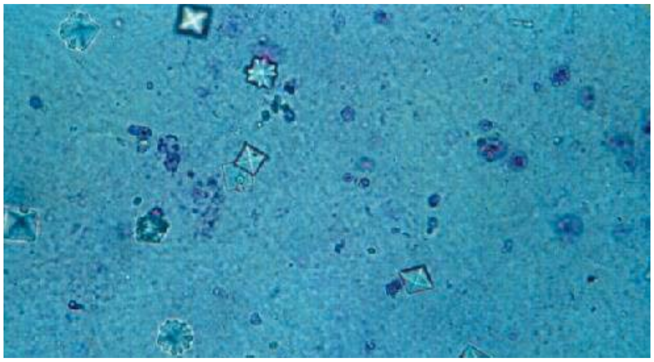

Figure 2: Micrograph showing calcium oxalate crystals in urine

A. The function of the kidney, as it relates to overall health, is extremely important since it plays a crucial role in keeping the blood clean and regulating the amount of fluid in the body. Waste products and excess fluid are removed from the body through the production of urine which involves highly complex steps of excretion and reabsorption. This process is necessary to maintain a stable balance of body chemicals.

I. Identify the primary filtration structure of the kidneys. Describe the process of blood filtration and how metabolic wastes and other toxic substances are removed from the body by the urinary system.

II. Explain how the kidneys' processes of filtration and reabsorption maintain the proper balance of water and electrolytes in the extracellular fluid.

B. In microgravity, decreased urine volumes are accompanied by increased urinary excretion of calcium. This greatly increases the chances of developing renal stones.

I. Discuss the role of calcium in the formation of renal stones.

II. Evaluate the health risks involved with developing renal stones during spaceflight.

III. Renal stones can usually be prevented by modifying fluid intake, adjusting the diet, and taking medication. Choose two of the three preventative measures listed below and explain how each could be used to lower the risk of renal stone formation in astronauts during spaceflight.

- Increasing the amount of water consumed during spaceflight
- Reducing the amount of salt in the astronaut's diet
- Taking potassium citrate supplements

C. Sulfur-containing amino acids in animal protein, as well as chlorides and phosphates in the diet, act as acid precursors. They are commonly associated with increased urinary calcium excretion and lower urine pH. Anions, including conjugate bases of organic acids, are base precursors. A diet high in sulfur-containing amino acids may increase acid load in the body and lead to the resorption (or loss) of bone mineral (calcium carbonate) and increased calcium excretion. This may result in an increased risk of renal stone formation due to an imbalance in the body's acid-base homeostasis.

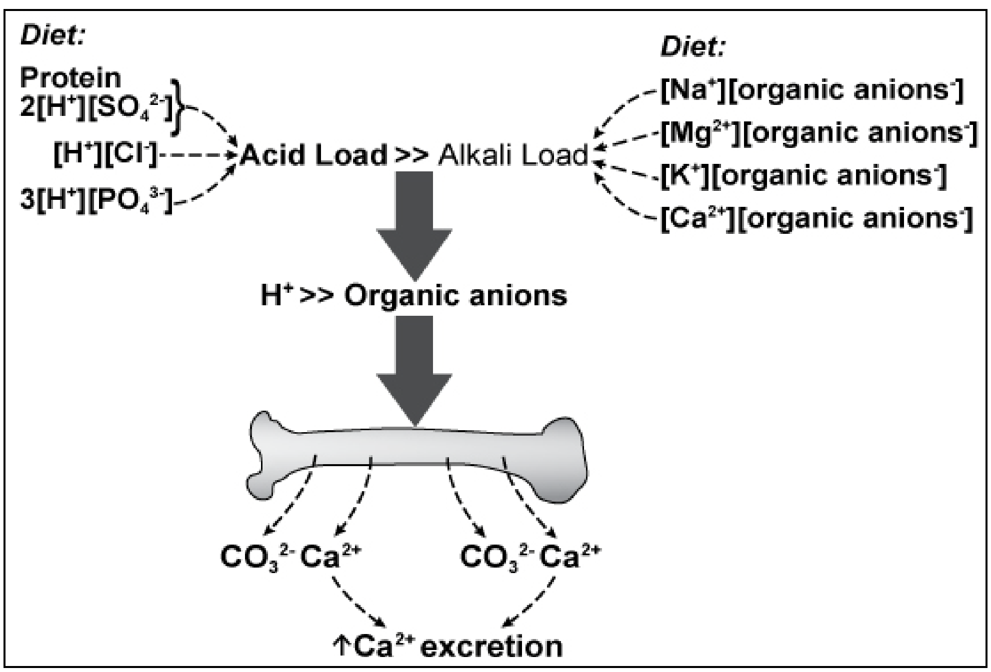

Figure 3: Schematic of acid-base homeostasis and the effects on bone of an increased acid load. Int. SportMed J. 6(4): 199–214 (2006)

I. If you were a dietician, what nutritional recommendations would you make to decrease the acid load and achieve acid-base homeostasis?

II. The presence of calcium in the body is critical to more than just bone formation. Explain the role that calcium plays in either skeletal or cardiac muscle contractions.