Ultratrace Minerals
Mythical Elixirs or Nutrients of Concern?

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Introduction

Ultratrace minerals is a term often applied to elements for which there is experimental evidence from animal models suggesting that they are essential for humans. However, the nutritional importance of these minerals has not been clearly established. One reason for the difficulty in establishing importance of ultratrace minerals is that they are required in such small amounts, 1 mg/day or less.

Since the early 1970s, there has been speculation that the lack of one or more of the ultratrace elements would be found responsible for some human diseases, such as atherosclerosis, osteoporosis and hypertension, without complete understanding of their cause. However, convincing evidence that ultratrace element deficiencies result in susceptibility to any disorders has been elusive. A possible explanation for this elusiveness is that previous experimental approaches were too simplistic. They usually involved a search for a simple deficiency that was unlikely to be found due to the powerful homeostatic mechanisms of the body.

When an organism is exposed to some form of nutritional, metabolic, hormonal or physiologic stress, some ultratrace elements may be of nutritional significance. In other words, the insufficient intake of a specific ultratrace element probably becomes apparent only when the body is stressed in some manner so as to enhance the need or interfere with the utilization of that element. Examining the possibility that some of the ultratrace elements are of importance for humans exposed to various stressors has revealed that boron and silicon are candidates of potential nutritional concern. The need for these minerals seems to be enhanced by human stresses, i.e., low dietary calcium and magnesium intakes or high dietary aluminum intake.

Boron Deficiency

Signs of boron deficiency in animals vary in nature and severity as the diet varies in its content of calcium, magnesium, cholecalciferol (vitamin D), aluminum, arginine and methionine. Nonetheless, boron deprivation affects a number of variables associated with calcium, copper and nitrogen metabolism. These effects ultimately alter the function or composition of the skeleton, kidney and brain.

Animals Studies

Calcium-deprived rats fed a boron (B) supplement of 3.6 or 12 μg B/g diet had vertebrae that contained higher calcium content and required more force to break than the vertebrae of rats fed a low boron diet. A basal diet containing 0.465 μg B/g diet supplemented with 3 μg B/g diet alleviated cholecalciferol deficiency-induced distortion of marrow sprouts of chick proximal tibial-epiphysial plate.

Dietary boron was found to influence the frequency distribution of the electrical activity in brains of mature rats. In this study, brain copper concentrations were higher in boron-deprived than in boron-supplemented rats. Furthermore, calcium concentrations in total brain and in brain cortex, as well as phosphorus concentration in the cerebellum, were found to be higher in boron-deprived than in boron-supplemented rats fed a cholecalciferol-deficient diet.

The apparent absorption and balance of calcium, magnesium and phosphorus were higher in boron-supplemented (2.72 μg B/g diet) than in boron-deprived (0.158 μg B/g diet) rats fed a cholecalciferol-deficient diet. Furthermore, a low boron diet increased the urinary loss of calcium and magnesium by female rats. The magnesium effect was enhanced by feeding low amounts of calcium.

Human Studies

Twelve postmenopausal women first were fed a diet that provided 0.25 mg B/2000 kcal for 119 days. They were later fed the same diet supplemented with 3 mg B/day for 48 days. The boron supplementation reduced total plasma concentration of calcium and urinary excretion of calcium and magnesium. Boron supplementation also elevated the serum concentrations of 17β-estradiol, testosterone and ionized calcium in these women.

Subsequently, an experiment was performed with men and women aged 45+ years. These subjects were depleted of boron for 63 days while fed a basal diet (0.23 mg B/2000 kcal). This regimen was followed by a 49-day repletion period in which the basal diet was supplemented with 3 mg B/day. Both depletion and repletion diets were low in magnesium (115 mg magnesium/2000 kcal) and copper (1.6 mg copper/2000 kcal). Serum calcitonin, 25-hydroxycholecalciferol, ceruloplasm, plasma copper and erythrocyte superoxide dismutase activity were decreased during the boron-depletion period. Serum creatinine, glucose and blood urea nitrogen were higher during depletion than repletion. The subjects displayed impaired performance in tapping, pursuit, search, counting and encoding tasks during boron depletion.

Electroencephalograms obtained during boron depletion indicated that low dietary boron depressed mental alertness.

Function of Boron

As yet, a biochemical function for boron has not been elucidated. However, evidence that has been reported is consistent with boron's direct association with membranes and involvement in the functional efficiency of plants. Because the response of experimental animals seems to be enhanced by nutritional stresses that alter membrane integrity (e.g., magnesium deficiency), it would not be surprising to find that boron influences macromolecular metabolism by affecting the regulatory role of a
hormone at the cell membrane level. Furthermore, because boron affects calcium absorption and excretion in animals and humans, the gastrointestinal tract and kidney may be the primary sites of boron action. Thus, dietary boron intake may influence some disorders that exhibit disturbed macromineral metabolism, e.g., osteoporosis.

**Dietary Intakes of Boron**

Human studies indicate that most subjects consuming about 0.25 mg B/day respond to boron supplementation. Thus, the requirement for boron must be higher than this intake level. A recent study with chicks indicated that this species requires about 1 μg B/g dry diet. If it is assumed that adult humans consume 500 g of a mixed diet daily (dry basis), a boron concentration of 1 μg B/g dry diet would result in an intake of 0.5 mg B/day. This value may be close to the average minimum requirement for humans. For many individuals, however, higher intakes of boron may be required because of exposure to stresses such as low dietary intake of calcium and magnesium. Thus, an intake of 1 mg B/day may be appropriate to assure optimal health. It is important to point out that until further research has been conducted, oral doses in excess of 10 mg B/day are not recommended.

Foods of plant origin, especially fruits, leafy vegetables, nuts and legumes are rich sources of boron. Wine, ciders and beer are also high in boron.

**Silicon Deficiency**

Most of the signs of silicon deficiency in chickens and rats indicate an aberrant metabolism of connective tissue and bone. The response to silicon deprivation can be enhanced by low dietary calcium and high dietary aluminum. Rats fed a diet low in both calcium and silicon and high in aluminum accumulated high amounts of aluminum in the brain. Silicon supplements prevented the increase in brain aluminum. When fed a low calcium diet, silicon-deprived rats exhibited depressed tibial and skull concentrations of calcium, magnesium and phosphorus.

**Function of Silicon**

Both the distribution of silicon in animals and the effect of silicon deficiency on the form and composition of connective tissue support the view that silicon functions as a biological cross-linking agent that contributes to the architecture and resilience of connective tissue such as collagen, elastin and mucopolysaccharide. Silicon also is involved in bone calcification, however, the mechanism of involvement remains unclear. Because silicon affects bone and brain composition, the nutritional importance of silicon demands further study, especially for aging humans.

**Dietary Intakes of Silicon**

Although the essentiality of silicon (Si) was suggested almost 20 years ago, the minimum requirement has not been ascertained for any animal. Deficiency signs in chickens were prevented by 180 μg to 200 μg Si as the silicate/g diet or about 26 mg to 52 mg Si/1000 kcal. However, other silicon compounds apparently are 5 to 10 times as effective as silicate per atom of silicon in preventing deficiency. Thus, if humans have a requirement for silicon, it probably is in the range of 5 mg to 20 mg Si/day. There is no evidence, however, that describes signs of toxicity when silicon is consumed orally.

The richest sources of silicon are unrefined grains of high-fiber content, cereal products and root vegetables. Foods of animal origin are low in silicon.

**Other Ultracept Elements**

**Arsenic**

Signs of arsenic deprivation in animals are altered by dietary transformations that affect the metabolic transformation of methionine to cysteine and to its metabolites. Arsenic may be involved in the formation of various metabolites from methionine, e.g., cystine, taurine. The need for arsenic may become apparent in animals and humans exposed to a stress that affects sulfur amino-acid metabolism.

**Nickel**

The response to nickel deprivation was enhanced in animals with an elevated propionic acid metabolism caused by elevated dietary intake of an odd-chain fatty acid. A vitamin B₁₂-dependent enzyme, methylmalonyl-CoA mutase, catalyzes the last step in the propionate pathway of branched-chain amino acid and odd-chain fatty acid metabolism. Perhaps a need for nickel by animals and humans will become evident under situations in which demands upon the vitamin B₁₂-dependent enzymes are elevated.

**Vanadium**

Recent findings indicate that vanadium is an essential element that has a biological role affecting iodine metabolism and thyroid function. Moreover, it has been found that alterations in thyroid status enhance the response of rats to vanadium deprivation. Thus, the need for vanadium by humans may become evident if they are exposed to stressors that cause a subnormal thyroid status.

**Summary**

Demonstration of the nutritional significance of the ultratrace elements has resulted from studies indicating enhanced need in organisms exposed to various metabolic, hormonal, physiological and nutritional stresses. These studies indicate that some ultratrace elements, namely boron and silicon, will be found to be nutritionally important. The dietary lack of these elements may result in suboptimal function and composition of bone and brain.

**References**