Boron: A Review of its Nutritional Interactions and Therapeutic Uses

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Abstract

Boron is a trace mineral which is found in highest amounts in fruits, vegetables, nuts, and legumes. Although it has not been demonstrated unequivocally to be an essential nutrient for humans, increasing evidence indicates that boron deficiency and supplementation exert measurable biological effects. Boron has been shown to impact mineral metabolism, brain function and performance, and selected hormone levels. Because of its impact on mineral metabolism and hormones associated with bone formation, boron supplementation is considered to be important in the prevention of osteoporosis. Epidemiological evidence suggests that adequate boron in the diet may also prevent arthritis. Limited clinical observations support a possible role for boron in the treatment of this condition.
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Introduction

Boron is a ubiquitous constituent of man's external environment, which typically occurs in nature as borates hydrated with varying amounts of water. Boric acid and borax are important boron-containing compounds.[1]

In trace amounts, boron is essential for the growth of many plants, and is found in animal and human tissues at low concentrations.[1] Although it has yet to be recognized as an essential nutrient for humans, recent data from animal and human studies suggest that boron may be important for mineral metabolism, brain function and performance, and prevention of both osteoporosis and osteoarthritis.

Sources

Because boron in plants is dependent on the availability of boron in the soil, the same food crop can vary greatly in boron content depending on where it is grown. In general, soils exposed to high degrees of precipitation have decreased levels of boron.[2] Food processing results in additional loss of boron.[3] Foods of plant origin, such as leafy vegetables, non-citrus fruits, nuts, legumes, and sea vegetables are considered to be the best source of boron.[1,4] Wine has also been shown to contribute appreciable amounts of boron to the diet.[5] A diet containing an abundance of these items should provide between 2-6 mg of boron per day.[4, 6]

Daily intake of boron is dependent upon several variables. Concentration of boron in water varies considerably according to geographic source. In some areas, boron in drinking water and water-based beverages may account for most of the total dietary boron intake. Individual

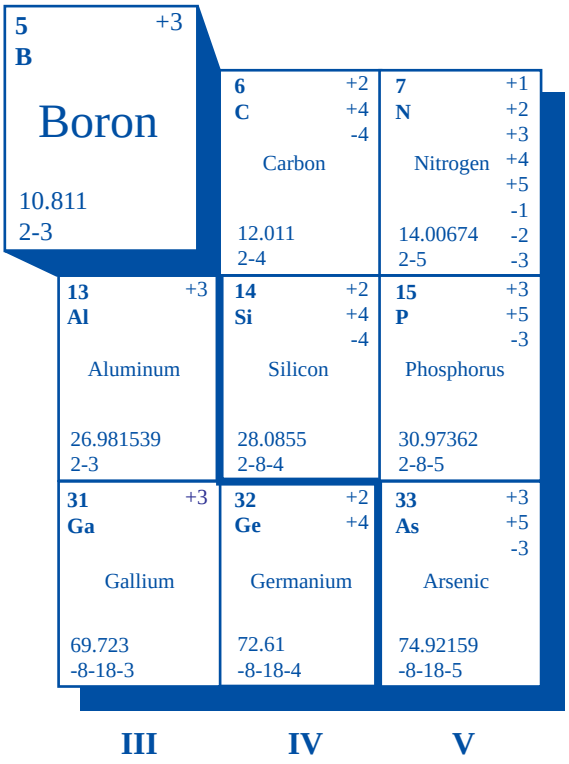
food preference greatly influences daily intake of boron. Fruits, vegetables, tubers, and legumes have relatively much higher concentrations of boron than do cereal grains or animal tissues. Boron has also been determined to be a notable contaminant or major ingredient of many personal-care products and it is occasionally used (boric acid) as a food preservative.[7]

In a recently published study, 32 subjects from Sydney, Australia, ages 20-53, were assessed over a 7 day period for their dietary intake of boron. The average boron intake in male and female subjects was found to be 2.28 +/- 1.3 and 2.16 +/- 1.1 mg/day, respectively.[5] The boron content of selected Australian foods has been found to correlate with values in Finnish and US Food and Drug Administration tables and is presented in table 1.

Chemical Properties

Elemental boron was isolated in 1808. It is the first member (atomic number 5) of the metalloid or semiconductor family of elements, which include silicon and germanium, and is the only non-metal of the group IIIA elements. Like carbon, boron has a tendency to form double bonds and macromolecules.[8] Boron, as boric acid, acts as a Lewis acid, accepting hydroxyl (OH^-) ions and leaving an excess of protons.[9] Because boron complexes with organic compounds containing hydroxyl groups, it is capable of interacting with sugars and polysaccharides, adenosine-5-phosphate, pyridoxine, riboflavin, dehydroascorbic acid, and pyridine nucleotides.[10]

Boron in the Periodic Table



Metabolism

Boron in food, sodium borate and boric acid are well absorbed from the digestive tract.[11] These compounds are also absorbed through damaged skin and mucous membranes, however, they do not readily penetrate intact skin.[12]

No accumulation of boron has been observed in soft tissues of animals fed chronic low doses of boron, however, in acute poisoning incidents, the amount of boric acid in brain and liver tissue has been reported to be as high as 2000 ppm. Within a few days of consumption of high amounts of boron, levels in blood and most soft tissues quickly reach a plateau.[13] Tissue homeostasis is maintained by the rapid elimination of excess boron primarily in the urine; with bile, sweat, and breath also contributing as routes of elimination.[10] In humans, urinary boron excretion increases over time in all boron-supplemented subjects who have been studied.[14]

Evidence suggests that supplemental boron does accumulate in bone, however cessation of exposure to dietary boron results in

TABLE 1. Concentrations of Boron in Selected Australian Foods.[5]

Food	Boron (mg/100 g)	Food	Boron (mg/100 g)
Almond	2.82	Hazel Nuts	2.77
Apple (red)	0.32	Honey	0.50
Apricots (dried)	2.11	Lentils	0.74
Avocado	2.06	Olive	0.35
Banana	0.16	Onion	0.20
Beans (red kidney)	1.40	Orange	0.25
Bran (wheat)	0.32	Peach	0.52
Brazil Nuts	1.72	Peanut Butter	1.92
Broccoli	0.31	Pear	0.32
Carrot	0.30	Potato	0.18
Cashew Nuts (raw)	1.15	Prunes	1.18
Celery	0.50	Raisins	4.51
Chick Peas	0.71	Walnut	1.63
Dates	1.08	Wine (Shiraz Cabernet)	0.86
Grapes (red)	0.50		

a rapid drop in bone boron levels. The half-life of boric acid in animals is estimated to be about one day.[13]

Biological Functions

It has been proposed that boron contributes to living systems by acting indirectly as a proton donor and that it exerts an influence on cell membrane structure and function.[15] Although the absolute essentiality of boron for plants is well documented, studies to date have not shown it to be unequivocally essential for either animals or humans. With this in mind, however, boron supplementation has been shown to affect certain aspects of animal physiological function.

Experimental animals supplemented with boron demonstrate a high degree of variability in their response. In general, supplemental dietary boron has most marked effects when the diet is deficient in known nutrients.[16]

Boron in an animal model has been shown to have an effect upon life span, however, the process is undefined. Extremes in dietary boron, both deficiency and excess levels, decreased the median life span of Drosophilia by 69%; while supplementing the diet with low levels of boron increased life span by 9.5%.[17]

Brain electrophysiology and cognitive performance were assessed in response to dietary manipulation of boron (approximately 0.25 versus approximately 3.25 mg boron/2000 kcal/day) in three studies with healthy older men and women. A low boron intake was shown to result in a decrease in the proportion of power in the alpha band and an increase in the proportion of power in the delta band. Other changes in left-right symmetry and brain wave coherence were noted in various sites indicating an influence on brain function. When contrasted with the high boron intake, low dietary boron resulted in significantly poorer performance ($p < 0.05$) on tasks emphasizing manual dexterity; eye-hand coordination; attention; perception; encoding and short-term memory; and long-term memory. Collectively, the data from these studies indicate that boron may play a role in human brain function, alertness and cognitive performance.[18]

Boron supplementation to human subjects, who had previously followed a dietary regimen deficient in boron, increased blood hemoglobin concentrations, mean corpuscular hemoglobin, and mean corpuscular hemoglobin concentration; and lowered hematocrit, red cell count, and platelet count.[19]

Boron also impacts mineral metabolism and has been shown to impact levels of certain hormones in human subjects. In the first

nutritional study with humans involving boron, 13 postmenopausal women first were fed a diet that provided 0.25 mg boron/2000 kcal for 119 days, and then were fed the same diet with a boron supplement of 3 mg boron/day for 48 days. The boron supplementation reduced the total plasma concentration of calcium and the urinary excretions of calcium and magnesium, and elevated the serum concentrations of 17 beta-estradiol and testosterone.[4]

In a study designed to determine the effects of boron supplementation on blood and urinary minerals in athletic subjects on Western diets, findings suggested that boron supplementation modestly affected mineral status.[14]

Deficiency Signs and Symptoms

Information on boron deficiency is very limited, especially in humans. It is thought that insufficient intake of boron becomes obvious only when the body is stressed in a manner that enhances the need for it. When the diets of animals and humans are manipulated to cause functional deficiencies in nutrients such as, calcium, magnesium, vitamin D, and methionine, a large number of responses to dietary boron occur.[20] There is evidence that suggests that more than 21 days on a boron deficient diet are required to demonstrate detectable effects in humans.[21] The variables that are changed, due to a boron deficient diet, abruptly improve about 8 days after boron supplementation is introduced.[4] While by no means being pathognomonic for a boron deficiency, blood urea nitrogen and creatinine have been found to be elevated during boron depletion, [22] so may be a useful marker of a dietary deficiency.

Nutrient Interactions

Vitamin D: There is considerable evidence that dietary boron alleviates perturbations in mineral metabolism that are characteristic of vitamin D3 deficiency.[23] After 26 days, chicks fed a diet inadequate in vitamin D exhibited decreased food consumption and plasma calcium concentrations and increased plasma concentrations of glucose, beta-hydroxybutyrate, triglycerides, triiodothyronine, cholesterol, and alkaline phosphatase activity. Supplemental boron returned plasma glucose and triglycerides to concentrations exhibited by chicks fed a diet adequate in vitamin D.[24]

In rachitic chicks, boron elevated the numbers of osteoclasts [25] and alleviated distortion of the marrow sprouts of the proximal tibial epiphysial plate; a distortion characteristic of vitamin D3 deficiency.[23] Higher apparent-balance values of calcium, magnesium, and phosphorus have been observed for rats fed a vitamin D-deprived diet if the diet is supplemented with boron.[16]

In men over 45 and postmenopausal women fed a low magnesium and low copper diet, supplementation with 3.25 mg of boron per day increased levels of plasma D2.[26]

Calcium: Boron supplementation has a favorable impact on calcium metabolism. A boron supplement of 3 mg/day markedly affected several indices of mineral metabolism of seven women consuming a low-magnesium diet and five women consuming a diet adequate in magnesium; the women had consumed a conventional diet supplying about 0.25 mg boron/day for 119 days. Boron supplementation markedly reduced the urinary excretion of calcium and magnesium; the depression seemed more marked when dietary magnesium was low.[4]

In men over 45 and postmenopausal women, changes caused by boron supplementation include; increased concentration of plasma ionized and total calcium, as well as reduced serum calcitonin concentration and urinary excretion of calcium.[26] A 1993 study

demonstrated that a low boron diet elevated urinary calcium excretion.[27]

Copper: Available evidence indicates that supplemental boron acts to increase serum levels of both copper and copper-dependent enzymes in humans. Boron supplementation (3 mg/day), to five men over the age of 45, four postmenopausal women, and five postmenopausal women on estrogen therapy who had been fed a low boron diet (0.23 mg/2000 kcal) for 63 days, resulted in higher erythrocyte superoxide dismutase, serum enzymatic ceruloplasmin, and plasma copper.[28] In a subsequent study, these same variables were again found to be higher during boron repletion than while subjects were fed a diet low in boron.[28]

Magnesium: When magnesium deprivation is severe enough to cause typical signs of deficiency, a significant interaction between boron and magnesium is found.[8] A combined deficiency of boron and magnesium causes detrimental changes in the bones of animals, however, supplemental boron elevated plasma Mg concentrations and enhanced growth.[25]

Boron supplementation has resulted in increased serum magnesium concentrations in human female subjects studied.[13] It has been shown that serum magnesium concentrations are greater in sedentary females whose diets are supplemented with boron than in exercising female athletes who are supplemented with boron.[29] This finding, while unexplained to date, may indicate an increased loss of boron through urine and perspiration during exercise.

Phosphorous: Supplemental boron seems to lower serum phosphorus concentrations in female subjects ages 20-27;[29] however, exercise training diminishes these changes,[13] again possibly indicating increased losses or an increased need for boron as a result of exercise. A low magnesium status along with supplementation of boron may depress the urinary excretion of phosphorus. This does not occur in women with an adequate magnesium intake.[4]

Methionine & Arginine: In experimental animals, a beneficial impact is consistently observed after boron supplementation when the diet contains marginal methionine and luxuriant arginine. Among the signs exhibited by rats fed a diet marginal in methionine and magnesium are depressed growth and bone magnesium concentration, and elevated spleen weight/body weight and kidney weight/body weight ratios. Findings indicate that the severity of these symptoms is alleviated with boron supplementation.[30]

Hormone Interactions

In rats, supplemental dietary boron substantially depressed plasma insulin, plasma pyruvate concentrations, and creatine kinase activity and increased plasma thyroxine (T4) concentrations. Boron supplementation also decreased plasma aspartate transaminase activity.[31] In animal experiments, boron supplementation offsets the elevation in plasma alkaline phosphatase caused by vitamin D deficiency.[22]

Nielsen hypothesized that boron might be required for the synthesis of steroid hormones as well as vitamin D. Because the biosynthesis of steroid hormones such as vitamin D, testosterone, and 17 beta-estradiol involves one or more hydroxylations and because of boron's ability as a lewis acid to complex with hydroxyl groups, he suggested that boron may facilitate the addition of hydroxyl groups to the steroid structures.[4] It has also been suggested that boron may act in an unspecified manner to protect hormones from rapid inactivation.[4]

An increase in dietary intake of boron from 0.25 to 3.25 mg/d has been reported to increase plasma 17 beta-estradiol by more than 50% and to more than double plasma

testosterone levels in postmenopausal women. The elevation seemed more marked when dietary magnesium was low.[4] In a subsequent study of healthy men, boron supplementation resulted in an increase in the concentrations of both plasma estrogen and testosterone; however, other published trials do not support these observations.[5]

Ten male bodybuilders age 20-26 were given a 2.5-mg boron supplement, while nine male bodybuilders age 21-27 were given a placebo for 7 weeks. Because both groups demonstrated significant increases in total testosterone ($p < 0.01$), lean body mass ($p < 0.01$), and one repetition maximum squat ($p < 0.001$) and bench press ($p < 0.01$), the authors concluded that the gains were a result of 7 weeks of bodybuilding, not of boron supplementation.[32]

Table 2 lists boron's impact on selected hormones in either animals and humans. Some of these interactions have only been demonstrated in animal models (*) while others have not been demonstrated unequivocally to date in all age and gender segments of a human population (**).

TABLE 2. Boron's Observed Impact on Selected Hormones

Hormone	Increases (with boron)	Decreases (with boron)
Alkaline phosphatase		+
Aspartate Transaminase *		+
Calcitonin		+
Cholecalciferol	+	
Creatine Kinase *	+	
17 beta-estradiol **	+	
Insulin *	+	
Super Oxide Dismutase	+	
Testosterone **	+	
Thyroxine *	+	

Clinical Applications of Boron

Osteoporosis: There is considerable evidence that both compositional and functional properties of bone are affected by boron status.[33] In experimental animals, histologic findings suggest that supplemental boron enhances maturation of the growth plate.[24] Boron is also found at the highest concentrations in growing and calcifying areas of long bones.[4] In two human studies,[4, 22] boron deprivation caused changes in indices associated with calcium metabolism in a manner that could be construed as being detrimental to bone formation and maintenance; these changes were enhanced by a diet low in magnesium. The author concluded that boron and magnesium are apparently needed for optimal calcium metabolism and are thus needed to prevent the excessive bone loss which often occurs in postmenopausal women and older men.[22]

Arthritis: It has been suggested that boron deficiency in food may be a contributing factor in some cases of arthritis.[34] In areas of the world where boron intake routinely is 1.0 mg or less per day, the estimated incidence of arthritis ranges from 20 to 70%, whereas in areas of the world where boron intake ranges from 3 to 10 mg per day, the estimated incidence of arthritis ranges from 0 to 10%.[34]

Analytical evidence indicates that persons with arthritis have lower boron concentrations in femur heads, bones, and synovial fluid when compared with persons without this disorder. There have also been observations that bones of patients using boron supplements are much harder to cut than those of patients not supplementing with boron.[3]

In 1961, the first anecdotal evidence suggesting that boron may be beneficial for osteoarthritis was presented when one patient had reduction of swelling and stiffness and

remained symptom free for 1 year following supplementation of 3 mg of elemental boron twice daily for 3 weeks. A human study also offers evidence that boron supplementation may be beneficial in the treatment of this condition. In a double-blind placebo-controlled trial of 20 subjects with osteoarthritis, 50% of subjects receiving a daily supplement containing 6 mg of boron noted subjective improvement in their condition. Only 10% of those receiving a placebo improved during the same time interval. There was greater improvement in the condition of all joints ($p<0.01$) as well as less pain on movement ($p<0.001$) in subjects receiving the boron supplementation.[35]

Clinical observations indicate that children with juvenile arthritis (Still's disease) improve with boron supplementation (6-9 mg per day) in 2-3 weeks, while adults with osteoarthritis may require between 2-4 months of supplementation before benefits are detected. Persons with rheumatoid arthritis may experience an aggravation of symptoms (Herxheimer response) for 1 to 3 weeks, but generally notice improvement within 4 weeks of beginning boron supplementation.[3]

Toxicology

Although boron is potentially toxic to all organisms, and, as boric acid and borax, has been used as a pesticide and food preservative, higher animals usually do not accumulate boron because of their ability to rapidly excrete it.[9] Authenticated cases of poisoning in humans have been few and have primarily been the result of accidental ingestion of insecticides and household products containing borates, or use of large amounts of boric acid in the treatment of burns.[36]

The improper use of boric acid-containing antiseptics is still one of the most common causes of toxic accidents in newborns and infants. Since boric acid is readily absorbed through damaged skin, it should not be applied topically to extensive wounds.[11]

In animals, chronic low-level boron exposure has been shown to cause reduced growth, cutaneous disorders and suppression of male reproductive system function.[37] Studies indicate that male rodents suffer testicular atrophy with dietary exposure to boric acid above 4500 ppm and have decreased sperm motility at all exposure levels above 1000 ppm.[38]

Goats orally dosed with toxic but sublethal amounts of boron show significant increases in packed cell volume, hemoglobin, inorganic phosphate, creatine phosphokinase, conjugated bilirubin, sodium, glucose, cholesterol, and aspartate transaminase. The following serum components were significantly decreased after boron dosing: alkaline phosphatase, magnesium, glutamyltransferase and potassium. There was also an elevation of cerebrospinal fluid monoamine metabolites.[39]

Humans given 100 mg of boron intravenously [40] or 270 mg of boric acid orally reported no discomfort and showed no obvious signs of toxicity.[41] Airborne exposures to boron oxide and its hydration product, boric acid, have been reported to cause respiratory and eye irritation.[42]

Common indications of acute boron toxicity include nausea, and vomiting and diarrhea which are blue-green in color.[43] Other symptoms seen with acute exposure are abdominal pain, an erythemetous rash involving both the skin and mucous membranes, stimulation or depression of the central nervous system, convulsions, hyperpyrexia, renal tubular damage, abnormal liver function and jaundice.[11] Increased urinary riboflavin excretion has also been reported subsequent to acute boric acid ingestion.[44] Symptoms of chronic intoxication include anorexia, gastro-intestinal disturbances, debility, confusion, dermatitis,

menstrual disorders, anemia, convulsions and alopecia.[11]

Because of its ability to increase the excretion of boron, in cases of toxicity, N-acetylcysteine is the preferred intervention.[45]

Dosage

The optimal dose of boron for prevention of osteoporosis and proper physiological function appears to be between 3-6 mg/day. While it is best to obtain boron by means of a diet with an abundance of fruits, vegetables, legumes, and nuts; persons whose diet is limited in these items should consider taking a supplement containing 3 mg of elemental boron. In persons with arthritis, a trial period of 2-4 months with a dose of 3 mg of boron three times daily seems to be indicated.

Summary

Although degrees of skeletal response to boron are modified by other nutritional variables that include calcium, magnesium, vitamin D, methionine and arginine, there is considerable evidence that both compositional and functional properties of bone are affected by boron status.

Findings suggest that boron is an important nutrient not only for mineral metabolism but for varied aspects of optimal health in humans. While all published trials are not in agreement on the impact of boron supplementation on levels of sex hormones, it seems evident that boron raises levels in postmenopausal women and may have a potential impact in other segments of the population.

Based on available information, boron appears to offer benefits in the prevention of osteoporosis and arthritis. It is also a safe and potentially-effective addition that should be considered as an option in any treatment regimen for arthritis.

References

1. Naghii MR, Samman S. The role of boron in nutrition and metabolism. *Prog Food Nutr Sci* 1993;17:331-349.
2. Houng K-H. The physiology of boron and molybdenum in plants. In: Okajima H, Uritani I, and Houng H-K. *The significance of minor elements on plant physiology.* ASPAC Taiwan, 1975:61-66.
3. Newnham RE. The role of boron in human nutrition. *J Appl Nutr* 1994;46:81-85.
4. Nielsen FH, Hunt CD, Mullen LM, et al. Effect of dietary boron on mineral, estrogen, and testosterone metabolism in postmenopausal women. *FASEB J* 1987;1:394-397.
5. Naghii MR, Lyons PM, Samman S. The boron content of selected foods and the estimation of its daily intake among free-living subjects. *J Amer Col Nutr* 1996;15:614-619.
6. McBride J. Banishing brittle bones with boron? *Agric Res* 1987;Nov/Dec:12-13.
7. Hunt CD, Shuler TR, Mullen LM. Concentration of boron and other elements in human foods and personal-care products. *J Am Diet Assoc* 1991;91: 558-568.
8. Nielsen FH. Boron - an overlooked element of potential nutritional importance. *Nutr Today* 1988;23:4-7.
9. Loomis WD, Durst RW. Chemistry and biology of boron. *BioFactors* 1992;3:229-239.
10. Zittle CA. Reaction of borate with substances of biological interest. *Adv Enzymol* 1951;12:493-527.
11. Nielsen FH. Ultratrace minerals: Boron. In: Shils ME, Young VR. *Modern Nutrition in Health and Disease.* Lea & Febiger, Philadelphia, 1988:281-283.
12. Reynolds JEF, ed. *Martindale-The Extra Pharmacopoeia.* London;1996:1680.
13. Moseman RF. Chemical disposition of boron in animals and humans. *Environ Health Perspect* 1994;102 Suppl 7:113-117
14. Meacham SL, Taper LJ, Volpe SL. Effect of boron supplementation on blood and urinary calcium, magnesium, and phosphorus, and urinary boron in athletic and sedentary women. *Am J Clin Nutr* 1995;61:341-345.
15. Barr RD, Barton SA, Schull WJ. Boron levels in man: preliminary evidence of genetic regulation and some implications for human biology. *Med Hypotheses* 1996;46:286-289.
16. Dupre JN, Keenan MJ, Hegsted M, et al. Effects of dietary boron in rats fed a vitamin D-deficient diet. *Environ Health Perspect* 1994;102 Suppl 7:55-58.

17. Massie HR, Whitney SJ, Aiello VR, et al. Changes in boron concentration during development and ageing of Drosophila and effect of dietary boron on life span. *Mech Ageing Dev* 1990;53:1-7
18. Penland JG. Dietary boron, brain function, and cognitive performance. *Environ Health Perspect* 1994;102 Suppl 7:65-72.
19. Nielsen FH, Mullen LM, Nielsen EJ. Dietary boron affects blood cell counts and hemoglobin concentrations in humans. *J Trace Elem Exp Med* 1991;4:211-223.
20. Nielsen FH. New essential trace elements for the life sciences. *Biol Trace Elem Res* 1990;26-27:599-611.
21. Nielsen FH. Facts and fallacies about boron. *Nutr Today* 1992;May-June:6-12.
22. Nielsen FH. Studies on the relationship between boron and magnesium which possibly affects the formation and maintenance of bones. *Mag Trace Elem* 1990;9:61-69.
23. Hunt CD. The biochemical effects of physiologic amounts of dietary boron in animal nutrition models. *Environ Health Perspect* 1994;102 Suppl 7:35-43.
24. Hunt CD, Herbel JL, Idso JP. Dietary boron modifies the effects of vitamin D3 nutrition on indices of energy substrate utilization and mineral metabolism in the chick. *J Bone Miner Res* 1994;9:171-182.
25. Hunt CD. Dietary boron modified the effects of magnesium and molybdenum on mineral metabolism in the cholecalciferol-deficient chick. *Biol Trace Elem Res* 1989;22:201-220.
26. Nielsen FH, Shuler TR, Gallagher SK. Effects of boron depletion and repletion on blood indicators of calcium status in humans fed a magnesium-low diet. *J Trace Elem Exp Med* 1990;3:45-54.
27. Beattie JH, Peace HS. The influence of a low-boron diet and boron supplementation on bone, major mineral and sex steroid metabolism in postmenopausal women. *Br J Nutr* 1993;69:871-884.
28. Nielsen FH. Biochemical and physiologic consequences of boron deprivation in humans. *Environ Health Perspect* 1994;102 Suppl 7:59-63.
29. Meacham SL, Taper LJ, Volpe SL. Effects of boron supplementation on bone mineral density and dietary, blood, and urinary calcium, phosphorus, magnesium, and boron in female athletes. *Environ Health Perspect* 1994;102 Suppl 7:79-82.
30. Nielsen FH, Shuler TR, Zimmerman TJ, et al. Magnesium and methionine deprivation affect the response of rats to boron deprivation. *Biol Trace Elem Res* 1988;17:91-107.
31. Hunt CD, Herbel JL. Boron affects energy metabolism in the streptozotocin-injected, vitamin D3-deprived rat. *Magnes Trace Elem* 1991-92;10:374-386.
32. Ferrando AA, Green NR. The effect of boron supplementation on lean body mass, plasma testosterone levels, and strength in male bodybuilders. *Int J Sport Nutr* 1993;3:140-149.
33. McCoy H, Kenney MA, Montgomery C, et al. Relation of boron to the composition and mechanical properties of bone. *Environ Health Perspect* 1994;102 Suppl 7:49-53.
34. Newnham RE. Agricultural practices affect arthritis. *Nutr Health* 1991;7:89-100.
35. Travers RL, Rennie GC, Newnham RE. Boron and arthritis: the result of a double-blind pilot study. *J Nutr Med* 1990;1:127-132.
36. Locatelli C, Minoia C, Tonini M, et al. Human toxicology of boron with special reference to boric acid poisoning. *G Ital Med Lav* 1987;9:141-146.
37. Minoia C, Gregotti C, Di Nucci A, et al. Toxicology and health impact of environmental exposure to boron. A review. *G Ital Med Lav* 1987;9:119-124.
38. Chapin RE, Ku WW. The reproductive toxicity of boric acid. *Environ Health Perspect* 1994;102 Suppl 7:87-91.
39. Sisk DB, Colvin BM, Merrill A, et al. Experimental acute inorganic boron toxicosis in the goat: effects on serum chemistry and CSF biogenic amines. *Vet Hum Toxicol* 1990;32:205-211.
40. Jansen JA, Anderson J, Schou JS. Boric acid single dose pharmokinetics after intravenous administration to man. *Arch Toxicol* 1984;55:64-67.
41. Aas Jansen J, Schou JS, Aggerbeck B. Gastrointestinal absorption and in vitro release of boric acid from water-emulsifying agents. *Fd Chen Toxic* 1984;22:49-53.
42. Garabrant DH, Bernstein L, Peters JM, et al. Respiratory and eye irritation from boron oxide and boric acid dusts. *J Occup Med* 1984;26:584-586.
43. Von Burg R. Boron, boric acid, and boron oxide. *L Appl Toxicol* 1992;12:149-152.
44. Pinto J, Huang YP, McConell RJ, et al. Increased urinary riboflavin excretion resulting from boric acid ingestion. *J Lab Clin Med* 1978;92:126-134.
45. Banner W Jr, Koch M, Capin DM, et al. Experimental chelation therapy in chromium, lead, and boron intoxication with N-acetylcysteine and other compounds. *Toxicol Appl Pharmacol* 1986;83:142-147.