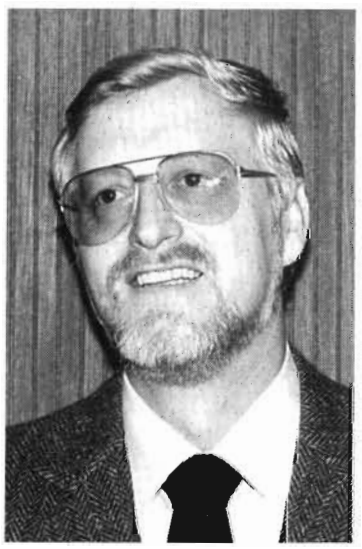
Facts and Fallacies About Boron

by FORREST H. NIELSEN, Ph.D.

Boron is of more nutritional importance than is generally recognized today, but is not a miracle nutrient as suggested by some recent claims. It is clearly a biologically dynamic element that affects numerous metabolic processes in higher animals, including humans.



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In 1987, a report, of which I was the senior author, described a nutritional study of the mineral element boron performed with postmenopausal women.[14] This study indicated that boron may be important for optimal macromineral metabolism in humans. I described the experiment and some research which preceded it, in *Nutrition Today*[9] in 1988, and suggested that boron may have a role in some disorders of unknown etiology that exhibit disturbed macromineral metabolism, such as osteoporosis. The response to these articles was astonishing and, at times, distressing or embarrassing to me and my collaborators. Within 3 months after the report appeared, boron supplements were being marketed. Shortly thereafter, all sorts of wondrous claims or headlines about boron began to appear in tabloids, magazines, advertisements, etc., some attributing the claim to me or a collaborator. Examples are seen in the box on page 7.

These statements have undoubtedly resulted in questions such as: Is boron the wonder substance it is touted to be, or are the health claims for boron just the handiwork of charlatans? What are the facts and fallacies about boron? I hope that most people realize that boron most assuredly is not the remarkable substance it is claimed to be by the reported headlines; however, accumulated evidence indicates that boron is of more nutritional importance than is currently acknowledged. Thus, it seems appropriate at this time to present some information that will delineate what we know about the beneficial or nutritional aspects of boron. In this discussion, "nutritionally important" means that dietary deprivation results in a suboptimal biological function that is preventable or reversible by physiological amounts of boron; "physiological" is defined as those quantities usually found in biological materials, including foods. "Pharmacological" means a relatively high oral intake of a substance that alleviates an abnormality caused by something other than a nutritional deficiency of that substance, or that alters some biochemical function or biological structure in a manner that may be construed as beneficial or desirable.

HISTORICAL ASPECTS OF BORON IN THE DIET

Boron always has been present in foods, especially in foods from

"Miracle Mineral (Boron)—Substance Could End Bone Disease in Gals"

"Incredible Strength Gains Using Awesome Boron"

"Stay Fit and Sharp with the Mystery Mineral (Boron)"

"It (Boron) Can Prevent the Side Effects of Aging"

"Boron. . .Corrects and Prevents Arthritis"

"Boron Is Effective in Suppressing Postmenopausal Hot Flashes"

"Boron Has a Very Positive Effect on the Male Libido"

"Boron—A Revolutionary Breakthrough in Nutrition"

plant sources, because boron is an essential element for plants. However, recognition of the benefits and detriments of boron in defined quantities in food seems to have begun in the 1870s. At that time, it was discovered that pharmacological amounts of borax and boric acid could be used to preserve foods. For about the next 50 years, borates were considered some of the best preservatives for extending the palatability of foods such as fish, shellfish, meat, sausages, bacon, ham, cream, butter and margarine. According to a recent historical review[3] of boron as a food preservative, an English Royal Commission, appointed in 1899 to investigate preservatives and colorings in foods, recognized in 1901 that borates were used as such for all foodstuffs except milk. At this time, except for its beneficial preservative property, boron was considered rather innocuous because no documented deaths resulted from the use of boron as a preservative. Actually, the well-being of humankind was enhanced by boron more during this time in history than most people currently recognize; it had a vital role as a preservative in preventing food crises during World War I.

Nonetheless, as early as 1902, German and American scientists began to question the orthodox view that large amounts of borates in foods were innocuous. Foremost among the works that changed perceptions about boron was a study with human volunteers performed by Wiley.[19] He reported in 1904 that when doses equivalent to over 500 mg of B/day for 50 days were consumed, disturbances in appetite, digestion and health occurred. Wiley concluded that 500 mg of B/day was too much for a normal man to receive regularly, and that 4,000 mg of B/day was the limit beyond which a normal man cannot go without harm. Subsequent to his report, the opinion that boron posed a risk to health gained momentum; by the mid-1920s many countries of the world began legislating against the addition of borates to foods. Only during World War II were the restrictions involving boron in foods eased; food shortages were making food preservation a major concern in many countries.[3] After the war, restrictions were gradually reimposed; by the middle 1950s boron was essentially forbidden throughout the world as a food preservative. Today, the direct addition of borates to foods either produced or imported by the United States is not permitted. It is quite amazing how one study at the turn of the century changed the attitude about boron. However, that study, combined with a few cases of misuse of boric acid in hospitals (such as applying boric acid on massive burns and open wounds which do not have skin to prevent entry into the body, and mistakenly feeding babies boric acid solution instead of sugar solution), created the general belief that boron was nothing more than a poison for humans. However, since the first human experiment involving boron was reported in 1987, the negative attitude toward boron seems to be changing to the recognition that boron, in small amounts, has some beneficial, if not essential, actions in humans. Unfortunately, with the change of attitude has come the fantastic claims based on limited data. Let's examine some of those claims, which are summarized in Table 1.

Wondrous claims or headlines about boron have appeared since 1988.

Boron in small amounts has some beneficial, if not essential, actions.

BORON AND OSTEOPOROSIS

In the 1987 human study[14] (Study I), 12 postmenopausal women first were fed a diet that provided 0.25 mg of B/2000 kcal for 119 days, and then were fed the same diet with a boron supplement of 3 mg/day for 48 days. The boron supplementation reduced the total plasma concentration of calcium and the urinary excretion of calcium and magnesium and elevated the serum concentrations of 17β-estradiol and testosterone. Based on these findings, it was concluded that boron, in amounts commonly found in diets high in fruits and vegetables, induces changes in boron-deprived postmenopausal women consistent with the prevention of calcium loss and bone demineralization, and that boron may be an important nutritional factor determining the incidence of osteoporosis. These words were almost immediately twisted to state that boron cures osteoporosis, or that consuming boron supplements will prevent osteoporosis. Common sense should prevent one from accepting these as unequivocal truths. Voluminous reports on the importance of smoking, alcohol, exercise, calcium, cholecalciferol, etc. in the susceptibility to osteoporosis should indicate that the dietary lack of one abstruse trace element is not the most important "cause of osteoporosis." Furthermore, the difficulty of restoring lost bone, or the impossibility of rebuilding a crushed vertebra, should indicate that boron cannot cure osteoporosis.

Table 1
Fallacies and Facts About Boron in Nutrition

Fallacy	Fact
Boron prevents and/or cures osteoporosis.	Boron deprivation induces changes that can negatively affect calcium metabolism and, thus, possibly enhances the susceptibility to osteoporosis. Boron deprivation depresses the response to estrogen ingested to prevent calcium loss or osteoporosis.
Boron supplementation increases muscle mass through increasing body testosterone.	Boron deprivation apparently has a negative impact on the ability to perform activities involving energy utilization, such as exercise.
Boron can stop memory loss and keep motor skills sharp; boron prevents the side effects of aging.	Boron deprivation is a slight depressor of motor function and cognitive performance. Boron deprivation causes electroencephalographic changes which reflect changes in mental alertness.
Boron corrects and prevents arthritis.	The connection between boron nutriture and the incidence or severity of arthritis is based mainly on hearsay, testimonial, circumstantial and weak epidemiological evidence.
Boron has been shown to be effective in preventing postmenopausal "hot flashes" and "night sweats."	Boron deprivation causes changes similar to that caused by a reduced estrogen status and depresses the response to estrogen therapy; estrogen is used to alleviate the discomforts associated with menopause. However, only a testimonial case report and hearsay evidence exist to support the claim that boron intake affects postmenopausal "hot flashes" and "night sweats."
Boron is a pharmaceutical.	Boron most likely is a nutrient which, when ingested in inadequate or excessive amounts, can have pathological consequences.

However, findings from studies subsequent to Study I still support the concept that inadequate dietary boron may be *one* factor that enhances the susceptibility to bone loss or osteoporosis because of direct or indirect effects on calcium metabolism. In one study (Study II),[15] five men over the age of 45, four postmenopausal women, five postmenopausal women receiving estrogen therapy and one premenopausal woman were fed a diet low in boron (0.23 mg/2000 kcal) for 63 days. Then they were fed the same diet supplemented with 3 mg of B/day for 49 days. The diet was low in magnesium (115 mg/2000 kcal) and copper (1.6 mg/2000 kcal) throughout the study. When all 15 subjects were used in the comparisons, plasma ionized calcium and serum 25-hydroxycholecalciferol were lower, and serum calcitonin and osteocalcin were higher during boron depletion than during boron repletion. The postmenopausal women receiving estrogen therapy exhibited higher plasma ionized calcium and serum 25-hydroxycholecalciferol and lower serum calcitonin and osteocalcin than did the men or postmenopausal women not receiving estrogen therapy. Boron supplementation apparently changed or tended to change those variables in a manner similar to that caused by estrogen therapy.

In another study (Study III),[12,13] men and postmenopausal women were subjected to the same experimental protocol as the one just described except that the diet was adequate in magnesium (315 mg/2000 kcal) and copper (2.4 mg/2000 kcal). Estrogen ingestion apparently increased serum immunoreactive ceruloplasmin and triglyceride concentrations; boron supplementation also increased the concentrations in all subjects. Additionally, when compared to subjects not receiving estrogen therapy, women ingesting estrogen exhibited elevated serum 17β-estradiol and plasma copper concentrations; the elevations were significantly higher during the high-boron than during the low-boron dietary period. Dietary boron did not significantly affect these two variables in the men and women not ingesting estrogen. These findings suggest that, in addition to mimicking some effects, boron can enhance some effects of estrogen ingestion in postmenopausal women. Thus, because estrogen ingestion is beneficial to calcium metabolism in postmenopausal women, boron may be beneficial through similar processes.

Boron can enhance some effects of estrogen.

Some recently reviewed[11] animal studies also support the concept that boron affects calcium metabolism. These include: 1) The apparent absorption and balance of calcium, magnesium and phosphorus were found to be higher with a boron-supplemented diet (2.72 μg of B/g) than with a diet deficient in boron (0.16 μg of B/g) in rats fed a diet deficient in cholecalciferol. Also, a low-boron diet increased the urinary loss of calcium and magnesium in female rats; the effect on magnesium was enhanced by feeding low amounts of calcium. When compared to calcium-deprived rats fed a low-boron diet, calcium-deprived rats fed a diet supplemented with 3, 6 or 12 μg of B/g had vertebrae that were higher in calcium content and required more force to break.

In summary, it seems fallacious to state that boron deprivation is the major cause of osteoporosis, or

that boron supplementation can reverse the consequences of postmenopausal calcium or bone loss. However, the factual evidence presented to date strongly suggests that a diet low in boron will depress the effectiveness of the only established effective therapy (estrogen ingestion) for preventing osteoporosis or will enhance the susceptibility of postmenopausal women to osteoporosis. Thus, the possible impact of boron nutriture on the treatment or prevention of osteoporosis should not be ignored.

BORON AND BODY BUILDING

The most surprising aftershock of the 1987 report[14] of Study I was the appearance of claims that boron could greatly build muscle mass and strength. These claims were puzzling until it was pointed out to me that in Study I, boron supplementation increased serum testosterone concentrations up to 300% in the postmenopausal women; increasing testosterone concentration is one method used to build muscle mass and strength. These claims for boron solicitously ignored three facts. First, the increases were found in postmenopausal women whose serum testosterone concentrations were normally very low. Second, the boron supplementation increased serum testosterone concentrations in women who had been deprived of boron for 119 days. Third, after boron supplementation restored serum testosterone to the apparently usual concentrations in the boron-deprived women, continued boron supplementation did not further increase the concentrations. In other words, the claims seem to intentionally mislead potential users of boron supplements to believe that boron was acting pharmacologically like anabolic steroids, instead of correctly pointing out that the data indicated boron was acting like a nutrient overcoming a suboptimal condition caused by a deficiency. The feebleness of the muscle building claims has been substantiated by the finding that the men in the human boron Studies II and III showed no significant changes in serum testosterone concentrations with changes in dietary boron (unpublished data). In addition, a recent 7-week supplementation trial showed no effect of boron on lean body mass, plasma testosterone concentrations or strength in male weight lifters.[1] Thus, the claims that supplemental boron can induce massive increases in muscle size and strength through increasing body testosterone should be considered fallacious.

However, recent findings by Hunt and Herbel[6] suggest that boron *nutriture* has an impact on energy metabolism during exercise training. Sedentary rats responded differently than rats exercised on a powered running wheel to changes in dietary boron. Exercise-trained rats, but not sedentary rats, exhibited higher body weights, serum lactate dehydrogenase activities and serum creatinine concentrations when fed supplemental boron (2.0 mg of B/g diet) than when fed a low boron diet (0.2 mg of B/g). Also, exercise training decreased blood urea nitrogen. In the human Studies II and III, blood urea nitrogen and creatinine levels were higher during boron depletion than during boron repletion. Moreover, boron deprivation was found to increase serum glucose and decrease serum triglyceride concentrations in humans and decrease serum glucose and triglyceride concentrations in rats. These findings suggest that the utilization of energy for exercise and the body's response to exercise training are changed by boron deprivation.

Claims seemed to intentionally mislead potential users of boron supplements.

In summary, it seems fallacious to state that boron supplementation increases body testosterone in such a way that it increases lean body mass and strength in humans. However, evidence is accumulating which suggests that low dietary boron may have a negative impact on the ability to perform activities involving energy utilization such as exercise.

BORON AND BRAIN FUNCTION

A recent popular magazine article stated: "Imagine never having to worry about the effects of another birthday. No, it's not a dream: researchers are finding that adding just a bit of boron to your basic diet can help stop memory loss, keep motor skills sharp and help you maintain a straight, youthful posture." That is, "it can prevent the side effects of aging." These words could be easily interpreted to mean that boron prevents aging or may be a substitute for the mythical fountain of youth. Here too, real research findings were the basis for these overzealous statements.

In the human Study II, Penland[16] obtained electroencephalographic, sensory-motor and cognitive performance data. During boron depletion, the subjects displayed slightly impaired performance in tapping, pursuit, search, counting and encoding tasks on a computer. Comparing electroencephalograms obtained during boron depletion with those during boron repletion indicated that low dietary boron depressed mental alertness.

Penland[16] also found that brain composition and function in rats were affected by boron deprivation. Dietary boron systematically influenced brain electrical activity assessed by an electrocorticogram in mature rats; the principal effect was on the frequency distribution of electrical activity. Brain copper concentrations were higher in boron-deprived than in boron-supplemented rats. Others[5] have found that calcium concentrations in total brain and in brain cortex, in addition to the phosphorus concentration in the cerebellum, were higher in boron-deprived than in boron-supplemented rats fed a cholecalciferol-deficient diet.

In summary, findings have been obtained which indicate that boron deprivation can negatively affect motor function and cognitive performance. Furthermore, inadequate dietary boron may alter brain composition and cause electrical activity changes which reflect changes in mental alertness. Hopefully, most readers would recognize the fallacy in translating these findings into evidence that boron can prevent the

side effects of aging or memory loss, or that taking a boron pill is all that is necessary to assure that one stays physically fit and mentally sharp.

BORON AND ARTHRITIS

The evidence to support the claim that dietary boron can affect the susceptibility to arthritis is questionable. The major proponent[8] of this claim has mainly based it upon weak epidemiological, hearsay and testimonial evidence. As with osteoporosis, the occurrence of the numerous forms of arthritis is dependent upon a number of factors; thus, stating that boron is a major, or the most important, factor in the incidence of arthritis, or can cure arthritis, seems preposterous. However, it may be prudent not to dismiss summarily the idea that boron could influence the extent or severity of some arthritic conditions. There are tidbits of information of acceptable quality that suggest that boron status may have some impact on some arthritic conditions. These include the following. Boron concentrations were lower in bones and synovial fluid from people with rheumatoid arthritis than from those without this disorder.[4] Findings from a small double-blind study suggested that boron helped some osteoarthritic individuals. Boron supplementation of 6 mg/day for 5 weeks was beneficial to 5 of 10 patients; only 1 of 10 patients improved with a placebo.[8] Animal data supporting the claim that boron can affect the arthritic process include the fact that amine cyanoboranes and amine carboxyboranes (synthetic boron analogues of α-amino acids) inhibited the induction of arthritis in rats (see review[10]). Also, boron alone and in combination with garlic oil showed antiarthritic activity against formaldehyde-induced arthritis in rats.[17]

In summary, based upon the limited factual information available, it is inappropriate to claim that boron can prevent or cure arthritis. However, the facts also indicate that it may be fallacious to state dogmatically that there is no connection between boron and arthritis. Thus, further study of this topic seems appropriate. If inadequate boron intake has an exacerbative effect, even a small one, on the symptoms of any form of arthritis, this knowledge would most likely be helpful to people who suffer from this painful and debilitating disease.

BORON AND MENOPAUSAL DISCOMFORTS

Soon after human Study I findings were reported[14] in 1987, I began receiving hearsay or testimonial-type evidence that a boron supplement of 3 mg/day alleviates the discomforts of menopause known as "night sweats" or "hot flashes." Among the unsolicited experiences related to me was that of one woman who found that a 3 mg of B/day supplement completely eliminated her hot flashes, which were occurring about two dozen times a night and leaving her exhausted. She reported only one episode of recurrence of the hot flashes in 1½ years; that occurred after she changed brands of boron supplements. She found that when she tried to dissolve the new brand in vinegar, "it just sat there"; the old brand dissolved quickly. This difference in dissolution was subsequently corroborated in my laboratory. Upon returning to the supplement that dissolved in vinegar, the woman was once again free of the hot flashes.

The idea that boron might affect the discomforts of menopause is not absurd.

The idea that boron might affect the discomforts of menopause is not absurd. Estrogen therapy is used to alleviate vasomotor, somatic and psychological changes associated with menopause. As described above, dietary boron sometimes has effects similar to estrogen and enhances some effects of estrogen therapy; this suggests that boron also may have some effects on vasomotor, somatic and psychological changes associated with menopause. However, to date, no double-blind crossover study examining a possible effect has been completed; one is currently underway at the Grand Forks Human Nutrition Research Center.

The lack of facts or data from a carefully controlled study does not allow for any conclusive statement about the importance of ingesting diets luxuriant in boron to alleviate discomforts associated with menopause. Scientific reasoning, a testimonial case report and hearsay evidence suggest that dietary boron could influence some discomforts. Thus, it seems appropriate to keep an open mind about this possibility.

OTHER HEALTH CLAIMS FOR BORON

Boron deprivation affects the function or composition of several body systems including the skeleton, kidney, brain and blood. The variables affected by boron deprivation are associated with the metabolism of several other nutrients including calcium, copper and nitrogen. With such a diverse array of effects, health claims for boron in addition to those discussed probably exist or will appear in the future. For example, I recently have been made aware of the claim that boron affects libido. The basis for this claim most likely is the finding that boron affects testosterone concentrations in postmenopausal women; enhanced libido has been associated with increased blood testosterone. Recently, some efforts have been made to associate boron epidemiologically with certain forms of cancer. Thus, it would not be surprising to see a claim relating boron to cancer.

When one sees health claims for boron, the following should be kept in mind: All data to date indicate that boron acts like a nutrient, not a pharmaceutical. In other words, a low intake of boron seems to affect negatively a number of indices associated with health and well-being. However, once adequate intakes of boron are achieved, further improvement in these indices do not occur with additional boron. Thus, taking boron supplements is not likely to cure or prevent any disease or disorder caused by something other than boron deprivation; boron is not a miracle nutrient or drug.

BORON TOXICITY

Chronic toxicity signs have been described for the rat, dog, duck, chick, cow and pig. Some of these signs indicate that high intakes of boron could have just the opposite effect of that desired by some people taking supplements. For example, when fed 8 mg of B/kg body weight/day (for a 70-kg person this would be equal to 560 mg of B/day), pigs showed signs of osteoporosis associated with a reduction in parathyroid activity.[2] Toxic intakes of boron (usually more than 1000 mg/kg diet) also have been shown to affect gonad development and function adversely in rats (see review[10]), to cause testicular atrophy in dogs (evidence of negative effects on testosterone metabolism) (see review[10]) and to increase feeding time[18] in ducklings (evidence of negative effects on the central nervous system).

Boron acts like a nutrient, not a pharmaceutical.

Although boron has a low order toxicity, it is like other mineral elements in that toxic intakes can be easily achieved through the excessive use of supplements. People should be cognizant of the fact that the volume of 1 mg of boron is equal to only a few grains of table salt, and that the consumption of amounts significantly greater than this would have detrimental consequences.

DIETARY CONSIDERATIONS OF BORON

The human studies described above indicate that most subjects consuming about 0.25 mg of B/day respond to boron supplementation. Thus, the basal requirement for boron must be higher than this intake. A study with chicks indicated that about 1 μg of B/g of dry diet meets the needs of this species. Extrapolation of this finding to humans, using the assumption that adult humans consume 500 g of a mixed diet daily (dry basis), would result in a requirement of 0.5 mg/day. The body most likely has a storage reserve for boron because there is evidence that more than 21 days are required to induce changes in humans by feeding low amounts of boron. Moreover, certain stressors common in everyday life (i.e., low intakes of magnesium and calcium) apparently increase the need for boron. Thus, a boron intake of greater than 0.5 mg/day seems desirable. Based upon animal studies and the fact that the value fits well within the range of intakes for populations that apparently do not have recognizable major boron deficiency concerns, a boron intake of 1 mg/day seems to be an appropriate recommendation to give to individuals seeking advice about the adequate intake of boron.

Chronic toxicity studies of boron that could be used to set a threshold toxicity level for humans is essentially nonexistent. The study of Wiley[19] established 500 mg of B/day as too high. Overt toxicity signs in animals generally occur only after the dietary boron concentration exceeds 100 μg/g. If it is assumed that adult humans consume 500 g of a mixed diet daily (dry basis), a boron concentration of 100 μg/g would translate into an intake of 50 mg/day. The richest food sources of boron, such as nuts and dried fruits, generally supply between 15 and 30 μg/g. A diet high in these foods plus wine (approximately 8.5 μg of B/ml) is not necessarily unusual; thus, a daily boron intake of 10 mg/day could be achieved through the diet. Until further studies clarify the issue, it seems prudent to accept the suggestion that 10 mg of B/day is not too high, but that an intake of 50 mg of B/day is.

A boron intake of 1 mg/day seems to be an appropriate recommendation.

As shown by Table 2, foods of plant origin, especially non-citrus fruits, leafy vegetables, nuts and legumes, are rich sources of boron. Wine, cider and beer are also high in boron. Meat, fish and dairy products are poor sources of boron. A limited number of surveys indicate that average daily intakes of boron range between 0.5 and 3.1 mg/day.

CONCLUDING STATEMENTS

In my 1988 *Nutrition Today* article,[9] I predicted that "much will be heard about boron in the near future and that boron will soon lose its classification as an overlooked or neglected element of potential nutritional importance." At least part of my prediction has come to pass; we

Table 2
Boron Content of Selected Foods*

Food	B (μg/g)
Fruits	
Apple juice	1.88
Apple sauce	2.83
Cherries, dark	1.47
Grape juice	2.02
Orange juice	0.41
Peaches, canned	1.87
Pears, canned	1.22
Wine	8.5
Dried Fruits	
Dates	9.2
Prunes	27
Raisins	25
Vegetables	
Beans, green	0.46
Broccoli, flowers	1.85
Broccoli, stalks	0.89
Lettuce, iceberg	≤0.015
Parsley flakes	26.88
Carrots, canned	0.75
Nuts	
Almonds	23
Hazelnuts	16
Peanuts	18
Meats	
Beef, round, ground	≤0.015
Chicken, breast, ground	≤0.015
Milk and Milk Products	
Cheese, cream	≤0.015
Milk, 2%	≤0.015
Cereal Grain Products	
Bread, white, enriched	0.20
Cornflakes, fortified	0.31
Flour, wheat, white	0.28
Rice, white, instant	≤0.015
Spaghetti, dry, enriched	≤0.015
Miscellaneous	
Catsup	0.85
Eggs	≤0.015
Honey	7.2
Jelly, strawberry	0.41
Jelly, grape	1.47
Sugar, white	≤0.015
Beverages†	
Wine	8.5
Cider	1.8
Beer	0.1

* Fresh weight basis. (From Hunt et al.[7] and Nielsen.[10])
† Boron in μg/ml.

are hearing much about boron. Unfortunately, some of what is heard was not expected and, because of its fallacious nature, has not been especially salutary to the reputation of the scientists associated with the human studies of boron, or to the establishment of boron as an element of *nutritional* importance. However, some good may come from the overzealous extrapolation of factual data or overstated health claims for boron. Perhaps the claims will stimulate further research into the nutritional, biochemical and physiological effects of boron. Such research would help in bringing about the second part of my prediction that boron will be found as an element of nutritional and, thus, clinical importance. This prediction seems promising because boron clearly is a biologically dynamic element that affects numerous metabolic processes in higher animals including humans.

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