Potential essentiality of boron: a ubiquitous dietary constituent

Sotirios Mangas and Samir Samman

Abstract The World Health Organization has classified boron as ‘a trace element that is probably essential’. Boron participates in or regulates a number of metabolic pathways including oestrogen and testosterone synthesis, calcium homeostasis and embryonic growth. Because of its involvement in steroid hormone metabolism, dietary boron has been suggested as having an important role in a number of chronic diseases and in vertebrate development. Extrapolations of data derived from experiments in animals suggest that humans have a boron requirement of 0.5 to 1.0 mg/day. There is uncertainty about the mechanisms through which boron acts. More research is warranted before boron is considered of more clinical and nutritional importance than currently acknowledged. Although there is uncertainty about the mechanisms through which boron acts, there is good evidence that it may impact on disease prevention. Future research should focus on defining the safety margin between toxic and essential doses and assess its possible therapeutic use. (Aust J Nutr Diet 2001;58:104–106)

Key words: boron, dietary intake, requirement, metabolism

Introduction

The regular intake of fruit, vegetables and legumes is encouraged in order to minimise the risk of chronic disease (1) and there are observational studies which support the hypothesis that the minor dietary components within these food groups are the active constituents (2). The presence of a large number of minor dietary factors reinforces the recommendation to increase the intake of whole foods rather than any specific supplement. However, the reductionist approach in nutrition research helps to elucidate the mechanism by which the components of food interact and impact on specific aspects of metabolism. While the attention on non-nutrients has centred mainly on flavonoids and phytoestrogens (3), there are inorganic components of food which have a potentially important role. The focus of this brief review is boron.

Sources of boron in the diet

Boron occurs widely in nature. Most of the earth’s soils have less than 10 µg boron per gram, with higher concentrations found in parts of the United States, Northern Chile and Turkey. Therefore, as for selenium, there appear to be geographical differences in the boron distribution in soils and nutritionists have to be aware of the source of food items when interpreting food tables (4).

Foods such as fruit, leafy vegetables, nuts, legumes, wine and cider are rich sources of boron (1.5–3.0 mg/100 g). Foods which are preserved in boric acid, such as caviar, are reported to contain high concentrations of boron (5). When portion size is taken into account, the analyses reported for Australian foods showed high concentrations were provided by avocado, legumes, dried apricot, peaches, prunes, raisins, prune juice, canned apples and hazelnuts (6).

Boron is also found in drinking water. The concentration in water fluctuates considerably according to its geographical source (7) and the concentration range in bottled water is 0.005 to 4.3 mg/L. The World Health Organization (WHO) previously derived 0.3 mg/L as a health-based guideline value for boron in drinking water. However, this value has been revised upwards to 0.5 mg/L (8). The Australian drinking water guideline for boron is also under review due to boron’s proposed essentiality status (9).

How much boron are humans consuming?

Nielson (10) recognised that fruit and vegetable consumption is associated with a high intake of boron. Analysis of foods and beverages from different countries has revealed the intake of boron is in the range 1.6 to 4.5 mg per day from a mixed diet and 2.4 to 7.0 mg per day for vegetarian diets in Europe; 10 mg per day in France; 1.7 mg per day in Finland; 0.8 to 5.5 mg per day in the UK; 1.5 mg per day in the USA and 1.3 mg per day in Canada (11). A number of surveys indicate that the average intakes of boron range between 0.5 and 3.1 mg per day (10) but the European Centre for Ecotoxicology and Toxicology of Chemicals (11) suggests a slightly higher range (1.3–4.5 mg/day). These differences can be explained partly by geographical differences in accordance to soil geochemistry and partly by methodological differences in the analysis of boron in food. A number of methods are available for the analysis of boron (12) but inductively coupled plasma analysis appears to be the analytical method of choice (4,9).

WHO estimates of boron consumption indicate the median, mean and 95th percentile daily intakes as 0.75, 0.93 and 2.19 mg per day, respectively, for all groups and 0.79, 0.98 and 2.33 mg per day, respectively for adults (13). The daily boron intake from the US diet has been calculated. The weighted 5th percentile, median, mean and 95th percentile boron intakes were estimated as 0.43, 1.02, 1.17 and 2.42 mg per day, respectively, for men; 0.33, 0.83, 0.96 and 1.94 mg per day, respectively, for women and 0.40, 0.86, 1.01 and 2.18 mg per day for pregnant women. For vegetarian adults, respective intakes were estimated as 0.46, 1.39, 1.47 and 2.74 mg per day for men and 0.33, 1.00, 1.29 and 4.18 mg per day for women. Although vegetarians consumed more boron-rich fruits, nuts and legumes they also consumed more low boron grain products and less total energy than non-

Public and Environmental Health Service, South Australian Department of Human Services, Adelaide, South Australia S. Mangas, BSc, GradDipEd, GradDipOHM, Scientific Officer Human Nutrition Unit, Department of Biochemistry, University of Sydney, New South Wales S. Samman, PhD, Senior Lecturer Correspondence S. Samman, Human Nutrition Unit, University of Sydney, NSW 2006. Email: S.Samman@biochem.usyd.edu.au
vegetarians (13). Consequently there was little variation in the median values between the two groups.

In the US population, the top two sources of boron in the diet were coffee and milk. These food items are low in boron, yet they account for 12% of the total boron intake by virtue of the volume consumed. Other beverages were also among the major contributors and these included: fruit-flavoured drinks, orange juice, apple juice, grape juice, cola drinks, wine, tea and beer. The top boron contributions from foods included peanut butter, wine, raisins and peanuts (14).

In Australia there are limited data on the dietary intake of boron. Naghii et al. (6) measured the daily boron consumption of university students and staff by using seven-day weighed food records and found an average intake of 2.2 mg per day. In a selection of Australian foods the boron concentration was found to be high (1.0–4.5 mg/100 g) in nuts, dried fruits, legumes and avocado; moderate (0.1–0.6 mg/100 g) in fresh fruit, vegetables and honey and low (0.01–0.06 mg/100 g) in foods from animal sources such as meat, cheese and butter (6). In the study, the daily mean intake of boron was found to be similar in men (2.3 ± 1.3 mg/day) and females (2.2 ± 1.1 mg/day). High amounts of boron in the diet were provided by avocado, legumes, dried apricot, peaches, prunes, raisins, prune juice, canned apples and hazelnuts. However, there may have been bias towards specific food groups in the female group. All the female subjects in the study were postgraduate students in nutrition and consumed relatively high amounts of nuts and vegetables that may have contributed to the high amounts of boron. Boron intake was also positively associated with the intake of dietary fibre.

Metabolism of boron

Boron is absorbed rapidly but very little is known about factors which affect bio-availability, the mechanism of its absorption or transport (4). The estimated boron content in humans is 3 to 20 mg (15,16). Boron distributes throughout the body water and the normal range in blood is 0.05 to 0.6 mg per litre. The deposition of boron has been observed in a range of tissues (4,15–21). The boron content in human spleen and liver is high (21). However, the physiological implications of the high concentrations in these tissues are not clear. There is no progressive distribution and accumulation in body tissues but the body probably has a reserve store of boron because there is evidence that more than 21 days are required to induce biochemical changes in humans by feeding a low boron diet (22).

Boron and its derivatives (boric acid and borates) do not appear to be metabolised via the liver in humans or in animals. No organic boron compounds have been identified and at least 90% or more of the ingested dose is excreted (4,23). The plasma half-life is reported to range from 4 to 28.7 hours (24).

Is boron essential for humans?

In humans, there is limited support for the hypothesis that boron is essential. Deprivation of boron results in physiological changes which are considered detrimental and are preventable or reversible by an intake of physiological amounts of boron (22,25). Nielsen et al. (25) conducted a study on men and post-menopausal women who received a diet of 0.2 mg of boron per day for 119 days followed by a boron supplement of 3 mg of boron per day. The low boron diet was composed of conventional foods but low in fruit and vegetables. Dietary boron was shown to improve calcium homeostasis by a reduction in the urinary excretion of calcium, a decrease in serum calcitonin and an increase in serum 25-hydroxycholecalciferol. Plasma testosterone and 17-β estradiol increased in men and post-menopausal women respectively. These results could not be reproduced in another study. However, a positive calcium balance was reported (26). One potential explanation for the discrepancy in the results is the relatively shorter intervention period in the latter report (26).

Boron is reported to lower the platelet count and reduce the risk of thrombosis (27). In men, 10 mg of boron (equivalent to approximately five times the average intake) induced a small but significant increase in plasma oestrogen concentrations and this may be one of the mechanisms by which fruits and vegetables (i.e. boron-rich foods) help to lower the risk of coronary heart disease (28).

Boron may have an impact on rheumatoid arthritis by its effect on increasing the synthesis of corticosteroids (29). Analogues of α-amino acids which contain boron inhibit inflammation and arthritis in rodents by increasing cyclic adenosine monophosphate levels which block the release of lysosomal enzymes (30).

Other studies have suggested boron plays a role in brain function and cognitive performance. Electroencephalographic data from individuals consuming a low boron diet, showed a significantly poorer performance on tasks involving manual dexterity, eye-hand coordination, attention, perception and memory (31).

The mechanism by which boron exerts its biological activity is unknown. It is hypothesised that boron stimulates hydroxylation and methylation reactions. Both these activities are required in the metabolism of steroid hormones (4). The possibility that boron has a role in some mammalian enzymatic reactions is based on the effect of boron on the activity of plant enzymes in vitro. In plants, borate competitively inhibits two classes of enzymes. One class is the pyridine or flavin nucleotide-requiring oxidoreductases such as aldehyde dehydrogenase and cytochrome b5 reductase. Borate competes for NAD (nicotinamide adenine dinucleotide) or flavin because of its affinity for cis-hydroxyl groups. The other class of borate inhibited enzymes in which borate binds to the active enzyme site includes chymotrypsin and glyceraldehyde-3-dehydrogenase.

There are insufficient data to conclusively establish boron essentiality in humans. However, the WHO classifies boron as a probable essential trace element and that inadequate dietary boron (< 0.2 mg of boron per day) may be a factor in susceptibility to osteoporosis. The WHO suggests that the basal requirement for boron is 0.5 mg per day and proposes the mean dietary intake to meet the normative needs of adults is 1.0 mg of boron per day. The WHO (22) suggests the threshold of toxicity is 20 mg of boron per day and calculates 13 mg of boron per day as the upper limit for the mean population (CV = 25%) and 1.0 to 1.3 mg boron per day for adults as an acceptable safe range.
Boron

Toxicology

The results of a risk assessment showed that exposure from boron in soil, diets and drinking water would not be expected to pose any developmental, reproductive or other health risk to the public (32). An acceptable daily intake (ADI) of 0.3 mg of boron per kilogram per day or 18 mg of boron per day for a 60 kg female has been estimated (33). Human exposure to boron appears to be well below an ADI of 18 mg of boron per day and would not conflict with the ingestion of boron which can be achieved by dietary means.

Conclusion

Boron appears to have a widespread metabolic role and there is growing evidence to suggest that it may be an essential nutrient (22,34). However, further research is warranted to elucidate the mechanisms through which boron may impact on disease prevention. Future research should focus on defining a safety margin between toxic and essential doses and assess its possible therapeutic use.

References

5. Franco V, Holac W. Preservatives and artificial sweeteners—collaborative study of the determination of boric acid in caviar by emission spectroscopy. JAOAC 1975;58:293–6.