Zinc

The aesthetic objective for zinc is *≤5.0 mg/L*. Zinc is an essential element and is generally considered to be non-toxic. Intake of zinc from food is more than sufficient to satisfy the recommended daily requirements. Drinking water is not regarded as an important nutritional source of this element. Water containing zinc at concentrations above 5.0 mg/L tends to be opalescent, develops a greasy film when boiled, and has an undesirable astringent taste.

General

Zinc is an abundant element and constitutes approximately 0.004 percent of the Earth's substance.[1] The most common zinc mineral is sphalerite (ZnS), which is often associated with the sulphides of other metallic elements, e.g., lead, copper, cadmium, and iron.[2] Zinc is also found as calamine ($ZnCO_3$) in carbonate sediments; other forms of zinc are usually products of the oxidation of sphalerite.[2,3]

During 1984, the zinc content of ores and concentrates produced in Canada was 1 207 098 tonnes; domestic zinc consumption was 150 528 tonnes.[4] Canadian zinc reserves in known deposits have been estimated at 20 492 700 tonnes.[4] The main use for zinc in Canada is for galvanizing iron and steel, which accounted for 40 percent of the zinc consumption in 1984. A further 20 percent went towards the production of brass plumbing and heating fittings, and 15 percent was used in the die-casting industry to produce builders' hardware and automobile fittings.[5] The remaining consumption of zinc is divided among many industries. Zinc oxide is used in the manufacture of paints, rubber, rayons, yarns, inks, matches, and chemicals; zinc "dust" is used in printing, textile dyeing, and fat purification, and for cementing metals in metallurgical processing; rolled zinc is used in ornamental work and batteries; and zinc salts are used as wood preservatives and pesticides.

Occurrence

Industrial and domestic emissions contribute a considerable quantity of zinc to the air and water environments. In Canada during 1972, primary iron and steel production accounted for the emission of 2690 tonnes of zinc (in the form of zinc oxide) to the atmosphere. Primary copper and nickel production contributed a similar quantity (2290 tonnes). Total industrial emissions of zinc amounted to 6340 tonnes. Fuel combustion from stationary sources (coal and heavy oils) added a further 134 tonnes. Transportation, solid waste incineration, and pesticide application contributed 794, 124, and 1.8 tonnes, respectively. Emissions from all sources for 1972 totalled 7400 tonnes.[5]

In a 1980 study, it was estimated that the annual contribution of zinc to the Canadian environment from natural and anthropogenic sources was 768 000 and 414 000 tonnes, respectively.[6]

Analyses for zinc in airborne particulate matter over urban areas showed concentrations ranging from 0.32 mg/g in Toronto to 5.40 mg/g in Vancouver.[7] Concentrations as high as 6 mg/g were found in dust along Toronto's waterfront.[8]

Analyses of the total suspended particulates in the air over Edmonton during 1978 and 1979 showed a mean concentration of 0.085 $\mu g/m^3$ with little seasonal variation. During one event in November 1978, the concentration reached 0.6 $\mu g/m^3$, possibly as a result of fugitive emissions from incinerators.[9]

In a 1982 survey across Ontario, the spatial pattern of precipitation and air quality regarding trace metal content, including zinc, was monitored.[10] The mean air concentration of zinc ranged from 0.019 $\mu g/m^3$ in the south to 0.007 $\mu g/m^3$ in the north. Similarly, the annual dry deposition of zinc ranged from 1.51 $\mu g/m^2$ in the south to 0.51 $\mu g/m^2$ in the north. The mean concentration of zinc in the annual precipitation ranged from 0.0083 mg/L in the south to 0.0055 mg/L in the north.[8] The trace metal concentration across Ontario showed a general decreasing trend from south to north. The quantity of zinc found in precipitation reflects the presence of zinc-emitting operations. The mean concentration of zinc in precipitation near Sudbury, Ontario, during 1972 to 1973 was 0.028 mg/L, but reached 120 mg/L during one rainfall.[11] The average concentration of zinc in rain falling in the United States was 0.107 mg/L.[12]

In unpolluted snow sampled in a remote area of northern Manitoba, the concentrations of zinc were less than 0.001 mg/L.[11]

The average soil concentration of zinc in Canada is 90 mg/kg.[7] A similar value was found in soils not associated with sulphide ores in New Brunswick.[13] The zinc content of representative soils from industrial locations in Canada ranged from 106 to 2095 mg/kg (the maximum value was found in Toronto).[8] Urban soil samples from Vancouver and Toronto contained 395 and 220 mg/kg, respectively.[7]

The carbonates, oxides, and sulphides of zinc are sparingly soluble, and therefore zinc is present in natural waters at low concentrations. The highly soluble chloride and sulphate salts are hydrolyzed to form the hydroxide and carbonate. Adsorption onto hydrolysate sediments further depletes the levels of dissolved zinc.[3]

The environmental concentration of zinc in Canadian surface waters ranged from 0.001 mg/L to a high of 1.17 mg/L over a 1980 to 1985 sampling period.[14] Analysis of several lakes in Ontario (used as sources of drinking water) showed that the mean concentration of zinc was less than 0.010 mg/L.[15]

In surveys of river water in central and western Canada, it was found that the level of zinc varied widely with both the location and the season. The range was 0.001 to 0.096 mg/L, with maximum levels observed in the Slave River in the Northwest Territories; normally, the concentrations in river water do not exceed 0.04 mg/L.[16]

The concentration of zinc can be considerably higher in tap water than in surface water because of the leaching of zinc from galvanized pipes, hot water tanks, and brass fittings.[17]

In a national survey of Canadian drinking water supplies, it was found that the median zinc content in the raw, treated, and distributed water samples rarely exceeded 0.01 mg/L. However, zinc was frequently picked up while passing through the distribution network. In New Brunswick and Saskatchewan, pickup was negligible, whereas in British Columbia and Quebec, pickup was found in over half the distribution systems.[18]

Recent data from Ontario have corroborated these findings, with zinc in water withdrawn after an overnight stand sometimes reaching levels 100 times greater than that of the treated water. Thus, in Gananoque on the St. Lawrence River, the concentration of zinc after treatment was less than 0.01 mg/L in 1986, whereas the mean concentration at seven stations after an overnight stand was 0.309 mg/L (range: 0.03 to 1.17 mg/L). Water sampled after a five-minute flush had a mean zinc concentration of 0.014 mg/L.[15]

Because of the nutritional value of zinc, several studies have been undertaken to determine the zinc content of foods and total diets. Two surveys have been carried out to establish the zinc content of representative Canadian diets. These showed that meat, fish, poultry, cereals, oils, and fats have the highest zinc content, with meat, fish, and poultry contributing most to the daily dietary intake.[19,20]

Canadian Exposure

The average daily intake from a “representative Canadian diet” has been estimated to be between 15.2 and 19.9 mg.[19,20] The average daily intake for a “normal” man was reported to be 12 mg,[7] whereas other estimates of the normal daily intake range from 13.0 to 16.1 mg.[21]

Based on a 1981 national survey of trace metals in drinking water supplies, it was estimated that the average daily intake of zinc from drinking water for Canadian adults is ≤13.0 µg/day.[18] Based on a 1984 study, this value ranged from 33.8 to 97.5 µg/day and was found to be highly dependent on the sampling strategy.[22]

If the average concentration of zinc in air in Canada is assumed to be 0.035 $\mu g/m^3$ and the daily respiratory volume 20 m^3, then the daily intake from air would be 0.7 µg.

Based on the above considerations, the total daily intake of zinc from food, air, and water is estimated to be about 16 mg, with food contributing over 99 percent of the intake.

Health Considerations

Essentiality

Zinc is an essential element for all living things, including man. Zinc-containing proteins and enzymes are involved in every aspect of metabolism, including the replication and translation of genetic material.[23] Nearly 200 zinc-containing enzymes have been identified from all species.[24] A few of the well-characterized zinc-containing enzymes are carbonic anhydrase, aspartase, transcarbamylase, and alcohol dehydrogenase.

The Recommended Dietary Intake (RDI) for Canadians is 2 mg/day for young infants, 3 to 7 mg/day for children to age 12, and, from the age of 13, 9 mg/day for males and 8 mg/day for females.[25] The United States Recommended Daily Allowance (RDA) is 15 mg/day for adults.[26]

Zinc deficiency is most often found in countries where the primary source of protein is cereal grains. Zinc absorption from these grains may be limited by high phosphate and phytate content.[27] Zinc deficiency, however, has also been identified in some children in the United States.[28] Zinc deficiency is most likely to

occur in segments of the population with high zinc requirements, such as infants, adolescents, and pregnant women.[29]

General symptoms of zinc deficiency in humans include retarded growth, hypogonadism, anorexia, mental lethargy, skin changes, and night blindness.[27] Zinc deficiency may also impair the immune system,[30–32] slow wound healing,[27,33] and lead to eczema[34] and acne.[35,36] The importance of zinc in brain development and function has also been emphasized.[37] Recently it was reported that hyperactive children showed some degree of zinc deficiency.[38]

Absorption

In humans, zinc is absorbed in the small intestine by a carrier-mediated mechanism.[39] The fraction of zinc absorbed is difficult to determine because zinc is also secreted into the gut. Generally, 33 percent is accepted as the average zinc absorption in humans,[25,40,41] although zinc may be more bioavailable from drinking water than from food.[42] Zinc absorption increases with increasing dietary zinc up to a maximum rate, indicating a saturated carrier-mediated mechanism.[43] In addition, zinc status may influence zinc absorption. Zinc-deprived humans absorb this element with increased efficiency, whereas humans on a high-zinc diet show a reduced efficiency of absorption.

Almost 20 regulatory and dietary factors have been reported to influence zinc absorption,[39] one of the most important of which is phytate (myoinositol hexaphosphate).[44] The bioavailability of zinc from cereals and legumes is greatly reduced by the phytate content of these foods,[40,45] although some components of dietary fibre may also reduce zinc absorption.[46,47] Phytate, particularly when ingested with calcium,[48] reduces zinc absorption by forming insoluble precipitates.

At high doses, zinc and iron appear to antagonize each others' absorption.[49,50] In addition, excessive levels of both tin and copper in the diet may reduce zinc absorption.[51–54]

Distribution

Zinc absorbed from the intestine is carried to the liver bound to albumin.[55] Within the circulatory system, between 80 and 90 percent of the zinc found in whole blood is in the erythrocytes,[56] where it is largely bound to carbonic anhydrase.[49] The remaining plasma zinc is primarily bound to albumin, although other proteins and free amino acids also bind zinc.[57] Only a small fraction of plasma zinc is in the ionic form.

The body tissues high in zinc include bone, liver, kidney, pancreas, retina, and prostate.[58,59] Redistribution of zinc can occur under stress.[60]

Excretion

Zinc is primarily excreted via the gastrointestinal tract; zinc excreted in this way consists of unabsorbed dietary zinc, endogenous zinc secreted into the gastrointestinal tract, and zinc from mucosal cell desquamation.[61] Excretory mechanisms contribute to zinc homeostasis; however, regulation of zinc absorption is the major homeostatic mechanism. Under normal circumstances, about 0.5 mg of zinc may be lost in perspiration,[62] and about an equal amount is lost in daily urine. Although the kidney nephrons appear capable of secreting and reabsorbing zinc, urinary zinc does not appear to fluctuate with diet.[63] High-protein diets, however, are reported to increase urinary zinc.[64]

Toxicity

Toxicity from dietary zinc has not been reported, although occupational exposure[65] or pharmacological interventions[66] can produce symptoms. There have been reports of teratogenic effects in sheep[67] and disrupted cholesterol metabolism in man,[68,69] both thought to be due to the adverse effects of high zinc concentrations on copper metabolism. The copper status of individuals consuming high-zinc diets, therefore, should be monitored. The immune response in humans is reported to be impaired by excessive zinc intake.[70]

Other Considerations

Taste threshold tests have shown that 5 percent of the population can taste zinc at about 5 mg/L.[71] At a concentration of 40 mg/L, zinc gives water a milky appearance.[72]

Rationale

1. Zinc is an essential element for human nutrition. The daily requirement is between 4 and 10 mg depending on age and sex, but pregnant women and new mothers may require up to 16 mg/day. Food constitutes the most important source of zinc. Long-term ingestion of quantities considerably in excess of these amounts has not resulted in adverse effects. Furthermore, because of efficient homeostatic control mechanisms, the occurrence of chronic zinc toxicity is extremely unlikely. A maximum acceptable concentration (MAC) for zinc in drinking water has therefore not been set.

2. Although surface waters seldom have zinc concentrations greater than 0.1 mg/L, levels in tap water can be considerably higher because of the use of zinc in plumbing materials. Water containing zinc at concentrations in excess of 5.0 mg/L has an undesirable astringent taste and may be opalescent and develop a greasy film on boiling.

3. The aesthetic objective for zinc in drinking water is therefore ≤5.0 mg/L.

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