

Trace elements found in various food stuffs, their clinical significance, deficiencies and importance in maintaining the health

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Abstract

For the maintenance of normal health, our diet requires adequate protein, energy substrates, vitamins and various inorganic salts and trace elements. None of the trace elements is required more than a milligram per day whereas the daily requirement for some is measurable in microgram. The WHO expert committee on trace elements in human nutrition (1973) has recognized 14 trace elements as essential for animal life: iron, iodine, fluorine, zinc, copper, cobalt, chromium, manganese, molybdenum, selenium, nickel, tin, silicon and vanadium.¹

Keywords: Trace elements; nutrition.

Definition

Those elements which have concentration less than 100 mg/dl in blood are known as trace elements. There are nine trace elements that are known to be required for optimum health. These are chromium, cobalt, copper, iodine, iron, manganese, molybdenum, selenium and zinc.

Iron

The total iron content in an adult body is approximately 4 g (70 mmol), of which about two-third is in haemoglobin. Iron stores (mainly spleen, liver and bone marrow) contain about one-quarter of the body's iron; the remainder is in myoglobin and other haemoproteins. Only 0.1% of the total body iron is in plasma where almost all is bound to a transport protein-transferrin.

Sources

Iron is widely distributed in food stuff.²

Animal sources are liver, meat, fish and eggs. They are not only important sources of readily available iron but also means of increasing the absorbability of iron in plant foods. The iron content in milk is low in all mammalian species. The average iron content of human milk is less than 1.0 µg/ml.³

Plant sources are cereals, pulses and vegetables especially green leafy vegetables. Other important sources are nuts, oilseeds and dried fruits such as raisin, apricots and dates. But the bioavailability of iron in plant food is low owing to the presence of phytates and oxalates which interfere with iron absorption.⁴

Absorption of Iron

Normally about 1 mg of iron is absorbed from food every day. Soluble inorganic salts of iron are easily absorbed from the small intestine. Gastric acid liberates free Fe³⁺ from non-heme iron compounds. Vitamin C and glutathione of food help in iron absorption by reducing Fe³⁺ to less polymerizable and more soluble Fe²⁺. Vitamin C and amino acid also help by forming soluble iron-ascorbate and iron amino acid chelates. Oxalates, phosphates and phytates of food reduce iron absorption by forming insoluble complexes of iron. Heme of food is absorbed as such in the intestine and degraded in the intestinal mucosa cells to release its iron.

Fe²⁺ absorbed into the intestinal mucosa cell is oxidized to Fe³⁺ which combines with a water-soluble cytoplasmic carrier called intra-cellular iron carrier.

Once absorbed into the intestinal mucosa cells, iron is either transported directly into the blood stream or else combines with apoferritin, a complex iron-binding protein to form ferritin. This iron is lost into the lumen of the gut when mucosal cells are shed. In iron deficiencies, the apoferritin content of mucosal cells decreases and a greater proportion of absorbed iron reaches the blood stream.

In the blood iron is transported bound mainly to transferrin; each molecule of which binds two Fe^{3+} ions. Transferrin is normally about one-third saturated with iron. In tissues iron is bound with ferritin and haemosiderin. Free iron is very toxic and protein binding allows iron to be transported and stored in a non-toxic form. Iron is lost from the body in faeces (Non-absorbed and shed mucosal iron) by desquamation of skin and in woman in menstrual blood loss. Very little iron is excreted in urine.

Deficiency

Iron deficiency results in hypochromic microcytic anaemic. Anaemia is also one of the causes of premature birth and increased neonatal death. That iron deficiency interferes with both cell-mediated immunity and bactericidal activity have been reported.⁵

Iron deficiency anaemia is one of the world's leading health problems. In Asia, about 10 per cent of men and 20 per cent of women (up to 40% among pregnant women) are reported to be anaemic.⁶ Iron deficiency anaemia occurs most commonly in growing children, during menstruation and pregnant women and in those having malaria. In developing countries, apart from increasing requirements, the commonest cause of iron deficiency are poor bioavailability of iron in the predominantly vegetarian diets and increased iron losses due to parasitic infection.

Copper

Copper is essential as it is incorporated in several enzymes. The amount of copper in an adult body is estimated to be about 100 mg.

Sources

Copper is widely distributed in nature. Even poor diets provide enough copper for human needs. Either deficiency or excess of this element is rare. Fish, oysters, liver, lentils, dry legumes and nuts are the sources of copper.

Function

Role in iron metabolism:

Copper helps in using iron for hemoglobin synthesis. Ceruloplasmin or serum ferroxidase, a blue copper protein complex of blood plasma, catalyzes the oxidation of Fe^{2+} to Fe^{3+} . This helps in incorporating iron in transferrin to facilitate mobilization of iron. A yellow copper-protein called non ceruloplasmin ferroxidase may also participate in the oxidation of Fe^{2+} in human plasma. Human infants, kept on unsupplemented milk diet poor in copper, may develop hypochromic microcytic anaemia with low protein bound iron in plasma, low serum copper and poor haemoglobin content. It does not respond to iron therapy, but a trace of copper, administered simultaneously with iron, promptly raises the blood reticulocyte count, haemoglobin concentration and serum protein bound iron.

Role in enzyme action:

Copper is present in prosthetic groups of metallo protein oxidases such as cytochrome oxidase, ascorbic acid oxidase, tyrosinase and uricase. Cytochrome oxidase activities are reduced in hepatic and mitochondria of copper-deficient chicken. A lack of hair pigments in copper-deficient sheep indicates reduced activity of tyrosinase in melanin synthesis.

Transport of copper:

After intestinal absorption, Cu^{2+} enters plasma and immediately binds with serum albumin. This copper albumin complex reacts directly with diethyldithiocarbamate to produce a colour (direct reacting copper). Much of the direct-reacting copper is soon removed by the liver from plasma combined with alpha globulins and released into the plasma again. This fraction of serum copper must first be liberated by HCl from the protein before it can produce colour with diethyldithiocarbamate (indirect reacting copper). The ratio between direct and indirect reacting fraction of serum-copper is usually 1:24. The indirect reacting copper mainly exists as ceruloplasmin or blue copper glycoprotein. The whole blood carries 100 $\mu\text{g/dl}$. The liver stores about 13-18% of the total body copper of 100-120 mg. Bile is the main channel for copper excretion.

Clinical condition:

A man may develop Wilson's disease due to an autosomal recessive genetic defect in either the synthesis of ceruloplasmin or the incorporation of Cu^{2+} in ceruloplasmin. The disease is characterised by low plasma copper, poor serum ferroxidase activity, low biliary copper, high urinary copper, high deposition of copper in the liver, pancreas, kidney, cornea and brain and consequently symptoms such as abnormal muscular movements, diabetes mellitus, renal tubular damage, a visible brown ring (Kayser-Fleischer ring) at the margin of the cornea, hepatic cirrhosis and jaundice. The patient ultimately dies of hepatic failure.

Menkes's disease is a fatal, sex-linked recessive disorder in which there are cerebral degeneration, connective tissue abnormalities and 'Kinky hair'. Both serum copper and ceruloplasmin are low and the copper content of the liver is very low. Absorption of copper from the intestine is impaired.

Hypercupremia may reflect excessive intake which may result from eating food prepared in copper cooking vessels or it may be associated with several acute and chronic infections, leukemia, Hodgkin's disease, severe anaemia, haemochromatosis, myocardial infarction and hyperthyroidism.⁷ An estimated copper requirement for adult is about 2 ug per day.

Zinc

Zinc is widely distributed in food-stuff, both animal and vegetables but the bioavailability of zinc vegetable food is low. Animal food such as meat, milk and fish are dependable sources. Unmilled cereals, legumes, maize, yeast, egg and oysters are also sources of zinc. Suggested daily intake for adults ranges from 5-10 mg.¹²

Absorption of zinc from the intestine appears to be controlled in a manner similar to that of iron. In plasma-zinc is mostly transported bound to albumin, alpha macroglobulin and transferrin and zinc is excreted in urine.

Zinc plasma level is about 96 ug per 100 ml for healthy adults and 89 ug/dl for healthy children.⁸ Zinc is stored in the liver, skin and bone. It is present in the RBC mainly as carbonic anhydrase.

The clinical manifestations of zinc deficiency include dermatitis and delayed wound healing. There is, however, no evidence of zinc supplementation accelerating wound healing in patient who are not deficient. Pregnancy lactation, old age and alcoholism have been reported as being associated with an increased incidence of zinc deficiency. Alcohol causes an increased loss of zinc in urine and plasma zinc is lower in chronic alcoholics than in normal individuals. Zinc deficiency may also be caused by diuretics, chelating agents and anti-cancer drug treatment. But deficiency in infants develop skin rashes and chronic diarrhoea and intestinal malabsorption.

Manganese

Sources

Cereals, vegetables, fruits, nuts, tea and liver. Manganese is stored in the liver. Blood contains 2-3 ug/dl. It is transported in plasma mainly in combination with a β 1-globulin called transmanganin.

It is a component of certain metallo-enzymes eg mitochondrial super-oxide dismutase, pyruvate decarboxylase; manganese ions activate a large number of other enzymes eg phosphatases, glycosyltransferases etc. These later include enzymes involved in the synthesis of glycosaminoglycans in bone and connective tissue.

Cobalt

An adult human body contains only about 1-2 mg cobalt. It is carried in plasma mainly in the cobalamin group of transcobalamin and is principally stored in the liver and excreted in the urine.

Functions

Cobalt may act as a cofactor for several enzymes such as glycylglycine dipeptidase of intestinal juice. As a constituent of Vit. B₁₂, cobalt also occurs in cobamine co-enzyme.

Cattle grazing in cobalt-deficient areas develop macrocytic anaemia curable by either vit. B₁₂ or cobalt sulfate. Continued administration of cobalt salts may greatly increase the number of circulating RBC (polycythemia). Cobalt is a constituent of vit. B₁₂, which helps in RBC maturation. Cobalt may also increase the production of erythropoietin. There is no evidence of cobalt deficiency in man yet.⁹

Chromium

Sources

Yeast, meat, cereals, milk and liver are the sources of chromium.

Total body content of chromium is small, less than 6 mg. There is suggestive evidence that chromium plays a role in relation to carbohydrate and insulin function.¹⁰ Cr³⁺ deficiency may lower the sugar tolerance and produce hyperglycemia in rats. This is prevented or cured by Cr³⁺ administration. Cr³⁺ may also increase sugar tolerance in human patients suffering from protein-energy malnutrition.

Selenium

Selenium, probably bound to protein, occurs naturally in all seafoods and those grains raised on selenium-containing soil. Fruits and vegetables are very low in it. Levels in most plants depend quite entirely on the level of selenium in the soil.¹¹

Trace elements in human and animal nutrition:

This is a component of erythrocyte glutathione peroxidase. The principal importance of this enzyme is to protect haemoglobin from being oxidised by hydrogen peroxide and other oxidizing agents (free radicals, super-oxides, organic hydroperoxides) that are the products of normal metabolism.

Selenium deficiency is the cause of Keshan disease, a cardiomyopathy, affecting children and young women in parts of China. A similar cardiomyopathy has been reported in a few patients on long-term parenteral nutrition, and in other patients, a skeletal muscle myopathy developed. Both type of myopathy responded to treatment with selenium supplements.

Selenium toxicity occurs in workers of paint, electronics, glass and ceramic industries. Ruminant animals grazing on selenium-rich soil may suffer from alkali disease.

Molybdenum

Source

Molybdenum is widely distributed in food in very small amounts. About the only foods known to contain as much as 0.6 part per million are legumes, cereals, organ meats and yeast.¹³

Function

A trace of molybdenum may help in using copper. But high molybdenum intake produces microcytic anaemia and low tissue copper in cattle and sheep. Excess absorption of molybdenum has been shown to produce bony deformities. On the other hand, deficiency of molybdenum is associated with mouth and oesophageal cancer.¹⁴ It occurs in several non-heme iron flavoprotein eg xanthine oxidase of the liver which oxidizes xantine to uric acid. It also occurs in hemoflavoproteins, sulfite oxidase of human liver and mitrogenase of nitrogen-fixing bacteria.

Nickel

Nickel is included among the essential trace elements largely on the basis of reports of its presence in serum protein in rabbits and man called nickeloplasmin.¹⁵ Nickel is widely distributed in plant foods.

Nickel deficiency in man has never been seen. It has not yet been proved to be needed by plants but is required by several microorganism.

Tin

Tin is included in the essential elements on the basis of its discovery in 1970 by Schwarz and Co-workers of its important growth promoting effect in deficient rate.¹⁶ It is widely distributed in foods of animal and plant origin.

Tin is not very toxics and if acid fruit juices or similar product dissolve appreciable amounts of tin from a tin plated can; it is not well absorbed by man (though the iron might be). High level of tin from 43-114 parts per million have been found in canned pineapple and citrous juices.¹⁷

The requirement for man is not known.

Vanadium

It is present in almost all plants and animals. But its amount in our food appears to be considerably lower than toxic level.¹⁸

No figure can be given for the vanadium requirements of man. But it maybe in the range of only 0.1 and 0.3 mg per day. No specific deficiency signs have been observed in rats other than poor growth. It is known to be a catalyst in several biological systems and to be present in higher than normal concentration in teeth.¹⁹

Silicon

Silicon has long been known to be required by certain lower forms of life and apparently by some plants, but its need by animal was unexpected. Edith Carlisle, nutritionist of the University of California reported in 1972 that silicon is needed in microgram amounts for normal growth and bone development in chicken.

Silicon is widely distributed in foods because of this deficiency in man would be virtually impossible on the basis of present knowledge of its distribution.

Fluorine

Fluorine is one of the most active elements of halogen group. It is never found free in nature. About 96% of fluoride in the body is found in bones and teeth.

Sources

Drinking water and tea are reliable sources of fluorine. Bone meal sometimes used as a mineral supplement is very rich in fluorine (normally 300-600 parts per million) and one cup of tea about 0.2-0.3 mg. Drinking water contains about 0.5 mg/l. But in fluorosis - endemic area the natural water have been found to contain as much as 3-12 mg/l.²⁰ Fluorine is not an essential element for plants so it is not always present in important amounts in food. Sea salt is not a reliable source, but breastmilk is very low though adequate. Fluorine tablets and fluorine taste are available which can serve as reliable though expensive source of this element.

Function

Fluorine occurs in human teeth in traces. It helps in tooth development, normal maintenance and hardening of the dental enamel and prevention of dental caries. But fluoride seems ineffective in curing caries and in mottling the enamel in fully formed adult teeth.

Fluoride occurs in bone in traces. Catalytic amounts of fluorides required for the conversion of calcium phosphates to appetite salts of bone and teeth. High fluoride intake enhances abnormal fluoride content, calcium deposition and density of bones.

High concentration of fluorides are extremely toxic and inhibits Mg^{2+} requiring enzyme.

Iodine

Sources

The best sources of iodine are seafoods and vegetables grown on iodine-rich soils. Water contains small traces of iodine. Milk, meat and cereals are the common sources. Some green leaves specially spinach are good iodine sources.

About one third to one fifth of the body iodine is collected in the thyroid which contains about 12 mg of iodine. About 99.8% of the thyroidal iodine exists as organically bound iodine, chiefly in thyroglobulin. Each 100 ml of plasma carries about 5.8 μ g of iodine bound to plasma protein and only about 0.3 μ g as inorganic iodides. Protein bound iodine rises and falls in hyperthyroidism and hypothyroidism respectively.

Function

Inorganic iodines are actively collected in the thyroid cells by an ATPase dependent iodide transport mechanism. Iodides are used in the synthesis of thyroid hormones. Dietary deficiency of iodide may produce thyroid enlargement (goitre and hypothyroidism).

Laboratory assessment

Unfortunately, the laboratory assessment of the body's trace elements is difficult as specialized equipment and considerable technical expertise is required. If plasma level is found to be very low, it may be useful in diagnosing and managing of disease. Similar changes are of less significance as for example, they may be due to changes in concentration of plasma protein which binds the metals. Great care has to be taken in collecting the specimens so as to avoid contamination because of minute concentration of the trace elements. Some of the instruments which can be used to measure the trace elements are:

- a. colourimeter
- b. atomic absorption of spectrophotometer
- c. ion selective electrodes

d. photofluorometer and

e. RIA (Radio Immuno Assay)

f. EIA

Trace elements like iron can be measured colourimetrically. But most of the trace elements can be estimated by atomic absorption spectrophotometer and ion selective electrodes. Fluorometric method whose sensitivity sometimes maybe 1000 times than that of colourimetric method, is used to measure trace elements like Mn. Iodine which can be estimated by RIA.

Nutritive value of trace element in different food stuffs is given below. In the Nepalese context, these values are yet to be found. For this, there is a need to set up research team at national level and necessary set up has to be done to carry out the research. This will also give a great assignment for differential diagnosis of trace element deficiencies.

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