

For more information on minerals see *Laboratory Evaluations in Molecular Medicine, Nutrients, Toxicants and Cell Regulators*, Chapter Three - "Minerals"

Since the body is unable to produce essential elements, those that are needed for function must be regularly consumed to make up for daily losses. Sometimes, however, exposure to elements that are needed in only very small amounts (or not at all) may be in excess and can cause toxicity. Measuring the trace element content of hair is a method of screening for possible health threats due to deficiencies or excesses of minerals. Hair reflects a longer interval of time than most tissues and body fluids.

Name		Metabolic Association	Potential Intervention
Highly Toxic Heavy Metals			(High Levels)
Arsenic	As	CNS, Hb, GI toxicity	Avoidance, chelation
Cadmium	Cd	Renal, CNS toxicity	Avoidance, chelation, Zn
Lead	Pb	Hb, CNS, toxicity	Avoidance, chelation, Ca
Mercury	Hg	PNS toxicity	Avoidance, chelation, Se
Potentially Toxic Elements			
Aluminum	Al	CNS, bone marrow toxicity	Avoidance, chelation, P
Barium	Ba	Radio-opaque materials	Avoidance
Boron	B	Potential bone formation	Ca, Mg
Lithium	Li	Neuropsychiatric effects	Dosage modification
Nickel	Ni	--	Avoidance, chelation
Strontium	Sr	Accumulates in bone	Ca, Mg
Essential Elements			Repletion Dose Ranges
Calcium	Ca	Myriad cellular effects	400 - 1,400 mg/d
Cobalt	Co	Vitamin B12 → Active cobalamin	200 - 400 µg/d
Copper	Cu	Detox. pathways	3 - 5 mg/d
Chromium	Cr	Insulin target cell binding	200 - 400 µg/d
Iron	Fe	Oxygen-binding proteins	10 - 50 mg/d
Magnesium	Mg	Phosphorylase enzymes	200 - 600 mg/d
Manganese	Mn	Biosynthetic pathways	5 - 15 mg/d
Molybdenum	Mo	Xanthine oxidase	1 - 5 mg/d
Phosphorus	P	ATP, etc.	---
Potassium	K	Muscle weakness	Fresh fruits & vegetables
Selenium	Se	Antioxidant protection	200µg - 3mg/d
Sodium	Na	Digestion, Nerve function	---
Vanadium	V	Cholesterol, triglycerides	200 - 400 µg/d
Zinc	Zn	Digestive enzymes & many others	15 - 50 mg/d

Highly Toxic Heavy Metals

Hair has a long history of successful use in detecting chronic exposure to toxic heavy metals in humans and animal models because hair concentrates heavy metals several hundred fold above concentrations found in blood. When any of the toxic heavy metals are elevated in hair, there is reason to investigate the origin of exposure. High levels in hair may reflect early chronic exposure before other signs and symptoms appear.

Elevations may be due to combinations of the following exposure:

1. Environmental or work-related exposure - Examples: welding, smoke exposure, painting, and printing
2. Use of heavy metal-containing products -

Examples: hair coloring treatments, artists paints, inks

3. Increased intestinal uptake - Examples: chronic digestive problems, malnutrition, or antibiotic use
Clinical manifestations vary with the level and duration of exposure and with patient health history. Managing high toxic metal body burden may require the following:

1. Avoidance of exposure.
2. Increased elimination by intravenous chelation or use a nutritional program involving increasing total dietary fiber intake to 30-40 g/day, methionine and cysteine at 3-4 g/day, and ascorbic acid at 3 g/day or more.
3. Ensured adequacy of competing nutrient minerals. If

lead is high, use calcium at 2 g/day. If cadmium is high, use zinc at 50 mg/day. For any toxic metal elevation, total nutrient trace element balance is needed.

4. Improvement of tissue turnover and regeneration by encouraging regular aerobic exercise and rest.

Arsenic (As)

Detection of elevated arsenic in hair may signify exposures threatening to health. The degree of health threat depends on the form of arsenic exposure. The presence of symptoms of toxicity would suggest testing of drinking water and other environmental sources of arsenic.

Arsenic exposure is associated with the following clinical symptoms:

- Neurological: Central depression with visual effects, headache, and high fever
- Hematological: Abnormal RBC counts, increased megalocytes and microcytes
- GI tract: Increased peristalsis with "rice water" stools
- Skin: "Milk and roses" complexion from vasodilation, darkening, and degeneration

Cadmium (Cd)

High hair cadmium is an indication of increased body burden. Associated conditions include:

- Renal -hypertension, kidney failure
- Neurological - loss of coordination, numbness of limbs, loss of hearing

Protection from toxic effects involves avoiding further exposure, implementing measures to reduce body burden, and assuring abundant intake of nutritional trace elements (especially zinc) and sulfur amino acids. Common environmental sources of cadmium are tobacco products and exhaust fumes. When a combination of high cadmium and low zinc is found, potential toxic effects may result because zinc competes for some protein binding sites that are sensitive to cadmium. A zinc deficiency can exacerbate the toxic effects of a high body burden of cadmium.

Lead (Pb)

Hair levels of lead are a good way to measure long-term lead exposure.

Common sources of lead in the environment are lead-pigment paints, industrial emission of airborne particles or water contamination, and occupations involving metal working or printing.

Health effects of lead are many and varied. Often the earliest sign is interrupted neurological development, especially in children, followed by chronic anemia from the metabolic interference of lead in hematopoiesis, results in lowered hemoglobin levels. Chronic anemia is associated with increased levels of the hemoglobin precursor zinc protoporphyrin in

blood, and the laboratory evaluation of RBC protoporphyrin (FEP) is a common screening for lead toxicity.

The potential toxic effects of lead may be prolonged by chronic negative calcium balance because lead absorption is higher when calcium intake is not adequate to maintain normal intestinal calcium concentration. Apparently, calcium competes with lead for absorption in the gut. Any further uptake of lead from ingested sources needs to be minimized. Individuals with high lead should increase dietary sources of calcium (e.g., milk, green vegetables, almonds, etc.) and consider calcium supplementation at 500 mg or more.

Mercury (Hg)

Hair mercury accurately reflects total body mercury content due to chronic exposure to this toxic metal. Elevations can result from chronic low level or acute toxic environmental or food exposure. High intake of contaminated fish (e.g., tuna) has been identified as a significant source, but fish are also a rich source of selenium, which protects against mercury toxicity. It is a good idea to eat fish from a variety of water sources and to avoid buying it regularly from the same place. Also, there is a growing concern over the potential release of mercury from dental amalgams.

A wide variety of symptoms ranging from growth retardation to neurological degeneration has been connected with chronic mercury elevation. Acute severe toxicity manifests as muscle and joint pain and possibly brain damage.

The combination of high mercury with low selenium is reason for additional concern about mercury toxicity. Selenium helps protect against toxic effects of mercury by competing with the binding of mercury to enzyme sulfur centers where much of the metabolic damage is done. Assure adequate selenium availability through diet or supplemental intake.

Potential Toxic Elements

These elements have no known function in human physiology, although they are present in the environment as airborne particles or in water and foods. Their detection in hair reflects their levels in soft tissues and bone, depending on total absorbed amounts. There are various reports of toxic effects when these elements accumulate, especially in the presence of specific disorders. For example, aluminum is known to produce toxic nervous system effects in cases of renal failure when patients are exposed to high levels in dialysis fluids. The toxicities are of much lower order of magnitude, compared to those of the "Highly toxic" elements discussed above.

Aluminum (Al)

Although hair aluminum may not accurately reflect total body burden of this element, there is growing concern over health threats from chronic high exposure of any sort, and a high value in hair probably reflects some regular source of exposure that should be eliminated.

There is some evidence connecting tissue accumulation of aluminum with onset of Alzheimer's disease, and some researchers have proposed a causal relationship. A more definitive test for aluminum elevation is not currently available.

Aluminum sources, such as antiperspirant (especially those in aerosol spray), aluminum-containing baking powders, and aluminum foil, can contribute to an elevated body burden of this toxic element.

Barium (Ba)

Barium is used in X-ray contrast media and in some salts for enemas. It is not a highly toxic element, so transient high levels in hair may be of small clinical significance. Many foods contain small concentrations of barium, and it responds somewhat like calcium, magnesium, and strontium to physiological controls. See strontium for more insight about high barium.

Boron (B)

The most common exposure of humans to boron is through cleaners containing borax. Boron is incorporated into bone, and (in some species) the process of bone formation is enhanced when a small amount of boron is provided.

Lithium (Li)

Lithium has known physiological impact on the cellular transport system of microtubules. The primary clinical use of the element is the administration of lithium salts to treat manic depression. Elevated lithium in hair is very rare since even therapeutic levels usually do not cause high concentrations in hair.

Nickel (Ni)

Nickel is not as toxic as the other non-essential elements reported here, but high levels in hair are found in individuals with either specific work-related exposure or general inability to tolerate normal exposures. Sources include stainless steel, tobacco smoke, industrial exhaust fumes, and batteries.

Strontium (Sr)

The stable isotope of the element strontium is commonly found in all natural dietary sources of calcium. The occurrence of this isomer is not related to the highly publicized radioactive strontium-90 that has been associated with fallout from nuclear blasts. Like calcium and magnesium, strontium is deposited in bone and mobilized from bone when blood calcium levels fall. Elevated levels in hair may signal negative calcium balance and, can provide a valuable marker for the risk of bone loss.

Essential Elements

All of these elements have essential function in human biochemistry. They are nutritionally essential and must be continually supplied by dietary sources to replace daily losses.

Abnormalities found in levels of essential elements in hair have varying significance in terms of the presence of current or recent past health threats.

Calcium (Ca)

In contrast to serum or plasma calcium, which does not vary except in serious pathologies, hair calcium displays a broad range of normal values. The fluctuations found reflect the ability of hair to accumulate calcium from the fluids of the hair follicle when the calcium is available in the ionized form. Factors that affect the levels of ionized calcium in blood can cause alterations in hair calcium over long time intervals.

Calcium accumulation in hair can reflect the end result of the process of chronic mobilization from bone. Thus, high levels are associated with calcium loss, which may indicate early signs of osteoporosis, especially in females in the age range of 30-50 yrs. High hair calcium in younger women may, by inference, indicate calcium loss that has not yet shown as bone density decrease.

Low hair calcium may indicate increased risk of myocardial infarction with increased associated aortic calcium concentrations. The implication for rapid advancement of the process of arteriosclerosis leads to several practical suggestions for maintenance of health

including a regular aerobic exercise program, quitting smoking, and eating fiber and foods rich in trace elements, especially whole grains and vegetables, on a daily basis.

In children, a manifestation of cystic fibrosis is the loss of calcium-binding ability of hair. Calcium levels in the hair of children are generally lower than in adults. During the active growing years, there is an altered distribution of calcium due to rapid uptake by osteocytes of bone. Thus, low hair calcium in children reflects calcium distribution, and is not directly related to dietary intake of calcium.

Cobalt (Co)

Very little data is available on clinical indications of high hair cobalt. We observe that multiple abnormal values for several elements are present most of the time when cobalt elevation is seen. Disorders of trace element homeostasis are suggested in such cases, but more research is needed to establish clear guidelines for following up on the finding.

Cobalt is required for the formation of vitamin B12 (cyanocobalamin), which is necessary for hair follicle function. Low hair cobalt may indicate B12 deficiency, but this needs to be substantiated with further research.

Copper (Cu)

Low hair copper offers evidence that either dietary copper is low or other conditions have diminished tissue copper supply. Copper functions include serving as cofactor in the processes of lipid metabolism, liver detoxication mechanisms, and neurological control.

Hair copper elevation has been associated with elevated systolic blood pressure. Some reports also have associated high copper with learning disabilities and other mental disorders. The production of the neurotransmitter noradrenaline depends on the copper-requiring enzyme, dopamine hydroxylase, which is released into extracellular fluids in response to nerve stimulation.

Excess dietary copper can lead to elevated hair levels. The hereditary disorder Menke's disease that affects soft tissue accumulation of copper does not generally manifest as elevated hair copper. Heavier exposure of the hair to copper-treated swimming pool water will give higher values, and this source should be ruled out.

The combination of high copper and low zinc makes the individual findings take on greater significance. These two elements are related in the way they impact body function, and clinical researchers have correlated imbalances of copper and zinc with dysfunction in lipid metabolism and neurological control.

Chromium (Cr)

Elevated chromium in hair is an unusual finding. Occupational or hobbyist exposure to chromium through paints, metalwork, or chemical use can cause elevation. Chromium may be present in detergents and bleaches. Exposure may be related to dermatitis because chromium is a common skin irritant in allergic eczema. Some forms of chromium (i.e., hexavalent) are highly toxic, but acute exposure to such compounds is rare outside of the chemical industry. The high incidence of allergies among construction workers may in part be related to the presence of chromium in cement.

Researchers have found low chromium in older age groups with senile dementia, suggesting that neuronal degeneration may be hastened with chromium deficiency.

Some studies have found low hair chromium in subjects with adult diabetes. Sugar metabolism was improved in over 80% of individuals who have a slight glucose intolerance by using 200 µg/d chromium supplement. The impact of this element on sugar metabolism is through its role in release of insulin. Losses of chromium in urine are related to increased mobilization in response to frequent blood sugar peaks.

Iron (Fe)

The iron in hair is unrelated to the major iron pool in the pathways of hemoglobin. The process of intracellular iron becoming incorporated into growing hair is poorly understood, but conditions of iron accumulation, such as hemochromatosis or hemosiderosis, do not appear to manifest as elevated hair iron. Long term chronic iron deficiency has been associated with low hair iron. Iron in hair might be revealing low cytochrome iron.

Magnesium (Mg)

Magnesium and calcium are associated in many ways in the body, and a strong relation between these elements in hair is also found. The association is primarily established in bone, where they are jointly used to form the mineral matrix of bone tissue. Under conditions where magnesium is being removed from bone at accelerated rates, blood components are shifted to supply the soft tissues, and the change is reflected as elevated hair levels.

Reactive hypoglycemia has been associated with low hair magnesium, and improvement was noted after magnesium supplementation.

Manganese (Mn)

Hair manganese has been shown to reflect dietary manganese in several studies. There are differences, however, among the normal manganese contents of hair of various colors. Red and black hair generally has higher manganese than white or gray hair, and standards for setting reference range differences for color are not yet available.

When hair manganese is high, sources of manganese may need to be investigated. Contaminated well water has led to toxic body burdens associated with neurological dysfunction in a rare instance of well water purifiers containing manganese.

Neurological disorders, such as epilepsy and Down syndrome, are extreme conditions that have been associated with low hair manganese. Although hair may not be the most sensitive monitor of nutritional status of manganese, it is advisable to assure adequate dietary manganese.

Molybdenum (Mo)

Molybdenum is present in the body in extremely small amounts and is difficult to measure. The enzyme xanthine oxidase in the pathway that converts purines into uric acid requires molybdenum. Low hair levels indicate need for molybdenum supplementation.

Phosphorus (P)

Little is known about the significance of hair phosphorus above reference range values. Thus, this element shows little variation among individuals, and high values are relatively rare.

Potassium (K)

Our own studies (unpublished) have shown an association between elevated hair potassium and signs of atherosclerosis. For example, the well-known risk factor, LDL/HDL cholesterol, is greater in individuals with high hair potassium. Since hypertension is often present in cases of known coronary artery disease where high hair potassium is found, there may be an indirect connection with the Na/K imbalance that leads to the blood pressure disorder.

Information on the clinical associations of low hair

potassium is limited. Studies with cystic fibrosis indicate that when there is normal potassium retention by the soft tissues, hair potassium remains normal or low.

Only when potassium retention becomes elevated does hair potassium show abnormal high values. Low values are frequently found in highly trained athletes and may indicate proper intake and utilization of this element. Low hair potassium associated with hyperadreno-corticism have been reported, but this is largely speculative needs to be substantiated.

A pattern of low calcium is sometimes found along with high potassium in adults. The association with advanced arteriosclerosis is considerably strengthened when such combinations are present.

Selenium (Se)

Applying the hair with selenium-containing shampoos will result in high selenium levels that do not reflect body status. Otherwise, elevated levels have not been shown to be clinically relevant.

Selenium functions primarily as an activator of enzymes necessary for protection from oxidative damage to the tissues and for maintaining normal redox potentials in the cells. The enzyme glutathione reductase is especially important in this regard as it keeps glutathione available for guarding against damage from oxidizers like superoxide radicals.

Sodium (Na)

High hair sodium indicates potential for impaired renal function. Electrolyte balance may be disturbed, causing excessive retention of sodium and accumulation in hair. Some evidence points to an association of chronic stress reaction with decreased hair sodium and/or potassium, possibly due to inadequate renal response to adrenal hormones.

Vanadium (V)

Vanadium levels can become high due to environmental exposure to chemicals containing this element.

The significance of values below the reference range for the element vanadium is not well established. Recent data identify vanadium as an essential element for humans.

Zinc (Z)

Elevations of hair zinc have been reported only during the special metabolic needs of pregnancy, where the high values were present with evidence of zinc deficiency. Such a "false" high value in a tissue like hair is not indicative of systemic elevation, but possibly of the system depletion. Inadequate dietary intake or absorption problems may cause zinc deficiency.

An imbalance in zinc and copper metabolism contributes to the risk of coronary heart disease (CHD). Some US diets have zinc-copper ratios in excess of those that produce hypercholesterolemia in rats. Also, the mortality rate for CHD was correlated with the ratio of zinc to copper in milk in 47 cities in the United States.

Nutritional zinc deficiency has been associated with low hair zinc levels. This trace element is one of the most widely distributed metals in the body, and metabolic effects of zinc deficiency are numerous. They include poor growth and healing, impaired inflammatory response, and reproductive dysfunction.

Highly trained female runners have increased risk for developing zinc deficiency due to suboptimal dietary patterns, high iron intakes (which restrict zinc absorption), and training-induced alterations in gastrointestinal function.

In the presence of low red cell zinc, a low hair zinc not only supports the suggestion of zinc deficiency but further gives evidence of the chronic nature of zinc depletion.

Body pools of zinc should be aggressively replenished via diet and supplementation. The upper range of therapeutic use of zinc supplements is 50-100 mg/day. Follow up testing in about three months should be done to monitor zinc status and assure that safe ranges are not exceeded at these levels of intake. Also, be aware of zinc interactions with other minerals, especially copper, which might be antagonized by the extra zinc.

In children, even mild zinc deficiency can be growth-limiting. Boys with hair zinc less than 110 ppm are likely to have lower body weight, reduced ability to taste, and possibly lower attention span.

