## Minerals

Minerals are naturally occurring compounds, often atomic elements, that are required for life. Similar to vitamins, minerals are not made by the body; they must be consumed in the diet or be supplemented. However, they are substantially different than vitamins because vitamins are organic while minerals are inorganic. Also, vitamins are often broken down by air, acid, or heat while minerals are not.

Most of the minerals relevant to humans are considered metals. These minerals are critical in bone structure, the antioxidant system, thyroid function, oxygen transport, and a host of other essential processes. Minerals are often overlooked in the diet, especially iodine, chromium, and copper. However, it is critical that people receive adequate mineral nutrition, which can be accomplished by consuming mineral-rich foods a few times a week.

### Calcium

The levels of calcium in the blood are very tightly controlled, with levels of calcium ranging between 8.4 to 9.5 mg/dL. Calcium plays a well-known role in the structural integrity of the skeleton; it is the critical mineral in the crystalline structure that makes up bone tissue. In addition to its structural role, calcium is also essential for skeletal muscle contraction along with other electrical signalling functions.

Calcium is an essential nutrient and must be consumed in sufficient quantities to prevent degradation of bone tissue and the development of osteoporosis. Calcium status of the body is so critical that there is an elaborate system of feedback loops that regulate calcium absorption. One way to think about calcium regulation is like a thermostat in a house: the temperature is set and a heater turns on and off to keep the temperature at that level. Calcium is controlled in a similar manner where absorption of calcium increases or decreases depending on how much the body needs (Figure: Calcium and the Body).

A cartoon of a person with text

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Vitamin D is involved in the active absorption of calcium from the digestive tract and absorption of calcium varies with the amount of calcium consumed. The relative amount of calcium absorption increases when calcium intake is low and decreases when calcium intake is high. For example, when calcium levels in the diets of women were decreased, the fractional proportion of calcium being absorbed increased (Dawson-Hughes, Harris, Kramich, Dallal, & Rasmussen, 1993).

### Chromium

Chromium is considered a trace element as the required intake is low (0.2 to 45 micrograms per day). There are two major forms of chromium: chromium 3+ (trivalent) and chromium 6+ (hexavalent). Chromium 3+ is the form found in food and is the biologically active form while chromium 6+ is a toxic form that results from industrial pollution (“Office of Dietary Supplements - Dietary Supplement Fact Sheet: Chromium”, 2018). Chromium deficiency is not well documented as there is no clinically defined level of deficiency and chromium is one of the most abundant minerals on earth.

Chromium has been implicated in regulating insulin signalling, with some data suggesting that it may enhance insulin sensitivity and/or decrease insulin resistance (Cefalu et al., 1999[)](https://paperpile.com/c/cZDv7y/QEEkX). Chromium works to improve insulin signalling by modulating chromodulin, a protein that augments the signalling of insulin receptors. While it is difficult to link chromium deficiency to diabetes or diseases of insulin resistance, there are several pieces of evidence to suggest that chromium, as a mineral, is likely involved to some extent in the development of diabetes (McIver, Grizales, Brownstein, & Goldfine, 2015; Rajpathak et al., 2004) (Figure: Chromium Sources).

A blue and white food sources

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### Copper

Copper is an essential mineral and helps balance the redox system in the human body. There are several disorders that come from copper metabolism issues. For example, Menkes disease results in seizures, brain atrophy, and hypotonia and is corrected by early copper supplementation. Copper is needed in minute quantities, ranging from 600 to 700 micrograms (0.6 to 0.7 milligrams) per day. Copper deficiency is exceedingly rare in humans and, in most cases, copper is consumed in adequate quantities in most dietary patterns.

### Fluoride

Fluoride is a non-essential mineral that, when consumed in low quantities, can be considered a beneficial ingredient for preventing cavities in teeth. Fluoride is found primarily in drinking water in the United States: roughly 52% of drinking water contains 0.7 to 1.2 mg/L of fluoride (Erdman, MacDonald, & Zeisel, 2012; Spector et al., 1995). While low doses of fluoride can reduce the risk of cavities, higher doses consumed chronically (>2mg/kg) can result in mottled and pitted tooth enamel. Furthermore, ingestion of 10 to 25 mg/day for extended periods of time (7 to 20 years) can damage bones. Currently, fluoride insufficiency is uncommon in humans and, in most urban and rural places, fluoride toxicity is rare and does not need to be a cause of concern.

### Iodine

Similar to chromium, iodine is considered a trace mineral that is found in some foods and is supplemented in many others such as iodised salt (“Office of Dietary Supplements - Iodine,” 2018). The primary function of iodine in the human body is as a precursor to thyroid hormones: both T3 and T4 (Figure: Function of Iodine). Iodine deficiency varies in prevalence due to geographic location as there are varying levels of iodine in the soil throughout the world. The most prevalent complications of iodine deficiency are goitre and hypothyroidism (Zimmermann, 2009[)](https://paperpile.com/c/cZDv7y/n8uHQ).

A diagram of the body

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Iodine deficiency and goitre were common in the Midwest United States through the early 1920s until iodised salt was made available in 1924 (Leung, Braverman, & Pearce, 2012). Iodine is critical to maintain proper thyroid function. In people who consume low-sodium/low-salt diets, careful attention should be given to ensuring adequate iodine intake.

### Iron

Iron is central in hundreds of metabolic processes, with the storing, transporting, and delivery of oxygen via haemoglobin and myoglobin being the most important of its myriad roles. Iron is also involved in the electron transport chain and neurotransmitter production (Alberts et al., 2002; “Anaemia | National Heart, Lung, and Blood Institute (NHLBI),” n.d.).

Iron deficiency prevalence varies from 5% in North America to upwards of 60% in Africa and is responsible for roughly 50% of all cases of anaemia (Stoltzfus, 2003). Iron deficiency is the primary cause of anemia, a condition in which your body does not have enough healthy red blood cells to transport oxygen (Figure: Iron-Deficient Countries).

A map of the world with different colored countries/regions

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Dietary iron is found in two major forms: haem and non-haem iron. Haem iron is derived from animal sources and is primarily made of haemoglobin and myoglobin. Non-haem is obtained from plants and other iron-fortified foods. While heme iron contributes roughly 15% of the total dietary iron intake, it contributes to more than 40% of all absorbed iron (Carpenter & Mahoney, 1992) (Figure: Sources of Iron Comparison).

A diagram of different types of iron

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Given the substantial role that iron plays in metabolism, specifically oxygenation and aerobic metabolism, and the relatively high prevalence of iron deficiency, there has been a substantial body of research examining the effect of iron supplementation on athletic performance. Much of the literature is focused on repletion of iron in iron-deficient women.

These studies demonstrate that in iron-deficient but not anaemic women, supplementation with iron improved their ability to adapt to aerobic exercise [(](https://paperpile.com/c/cZDv7y/pghjk)Brownlie, Utermohlen, Hinton, & Haas, 2004; Brownlie, Utermohlen, Hinton, Giordano, & Haas, 2002; Brutsaert et al., 2003). This indicates that iron likely plays a role in athletic performance and athletes, especially female endurance athletes, should be tested for iron deficiency.

Coach's Corner

Research indicates that correcting iron deficiency through supplementation (and potentially dietarily through food) can improve athletic performance. This does not mean supplementation above and beyond or if one is not deficient will help improve athletic performance.

### Magnesium

Magnesium is involved in over 300 biochemical reactions that span the full spectrum of human metabolism: from digestion to nervous system activity to glucose regulation and protein synthesis (“Office of Dietary Supplements - Magnesium,” 2018). Like calcium, magnesium is found in large quantities in the human body, with roughly 20 to 30 grams found in the average adult human. It is distributed as follows: 60% is found in bone tissue, 20% in skeletal muscle, 19% in other soft tissues (e.g., heart, liver, and lungs), and less than 1% is found in extracellular fluid (Swaminathan, 2003) (Figure: Distribution of Magnesium[)](https://paperpile.com/c/cZDv7y/5Tniz).

A diagram of a person with text

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Magnesium is conjugated to ATP; most ATP in the human body is found as MgATP. It is also intimately involved in the metabolism of carbohydrates, fats, and proteins and in the ion channels that regulate calcium flux and potassium flux across membranes. Additionally, evidence over the last 20 years has highlighted the role of magnesium insulin resistance.

Magnesium is important in many chronic diseases, specifically diabetes. People with Type 2 diabetes are more likely to have lower levels of serum magnesium and supplementation with magnesium has been shown to improve glucose metabolism and markers of insulin sensitivity (Arpaci et al., 2015; Rodríguez-Morán & Guerrero-Romero, 2003).

A recent meta-analysis also showed that magnesium supplementation lowered fasting glucose, LDL-c, and triglycerides and raised HDL-c in people with Type 2 diabetes (Verma & Garg, 2017). Magnesium should be given special attention in your diet and individuals should consume magnesium-rich foods such as whole grains, cocoa, spinach, and nuts. Supplementation can also be considered in individuals with very-low levels of magnesium.

### Mercury

Mercury is a trace element that finds its way into the human diet, has no necessary function, and is highly toxic, especially during development in utero and early childhood. The maximal daily intake of mercury recommended by the World Health Organization (2017) is 2 µg/kg per day. Mercury exerts its toxic effects primarily via the displacement of selenium (Carvalho, Chew, Hashemy, Lu, & Holmgren, 2008).

The largest source of dietary mercury is from seafood, including fish and shellfish. Mercury concentrations increase the further one goes up the food chain. Fish and shellfish that consume smaller fish with mercury in their blood and tissue store more mercury per tissue volume than smaller fish. As such, fish such as sharks, swordfish and tuna have higher levels of mercury than smaller fish such as mackerel (Mahaffey, Clickner & Bodurow, 2004) (Figure: Mercury Levels in Fish).

A screen shot of a fish chart

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### Phosphorus

Phosphorus is found everywhere in the body and is required for energy production and maintaining cellular viability. Phosphorus is the central molecule in phosphate, which is part of adenosine triphosphate (ATP), the energy molecule that facilitates virtually every biochemical reaction. Phosphorous deficiency is exceedingly rare in the United States and does not appear to be a major concern in most health conditions (McClure, Chang, Selvin, Rebholz & Appel, 2017).

There is some evidence that excessive phosphorus intake from processed foods may increase the risk of cardiovascular disease and osteoporosis and accelerate established kidney disease; however, these data are mostly observational in the broad public, with the exception being kidney disease. In people with kidney disease, the ability to clear excess phosphorus from the body is impaired and elevated levels of phosphorus are associated with increased risk of progression to end-stage renal disease (O’Seaghdha, Hwang, Muntner, Melamed, & Fox, 2011; “Serum Phosphorus and Death or Progression to End-Stage Renal Disease in Persons Screened in the Community for Chronic Kidney Disease,” 2013; Palmer et al., 2011[)](https://paperpile.com/c/cZDv7y/5Gxqp).

Currently, there is no evidence that phosphorus supplementation improves athletic performance; it does not need to be supplemented or a major focus for performance nutrition (Jones et al., 2017).

### Potassium

Potassium is present in all tissues in the body and is required for maintaining concentration gradients, fluid volume, and cardiac rhythm (“Office of Dietary Supplements - Potassium,” 2018). Potassium is present in relatively large quantities, with roughly 140 grams residing in a grown adult. Most potassium is present inside of cells with small amounts in circulation, with the ratio of intracellular to extracellular potassium being 30:1 (Hinderling, 2016[)](https://paperpile.com/c/cZDv7y/ZNB2o).

Severe potassium deficiency, known as hypokalaemia, can be deadly and cause cardiac arrest. Similarly, hyperkalaemia can also result in cardiac arrest (Jain et al., 2012). Potassium deficiency is rare in otherwise healthy adults without established kidney disease. There has been some discussion that potassium may prevent cramps; however, this has not been supported by scientific literature.

### Selenium

Selenium is the key component of several selenoproteins that serve as antioxidants or in the regeneration of antioxidants. Specifically, thioredoxin reductase and glutathione peroxidase are selenoproteins. Mercury exerts its toxicity in the human body by displacing selenium and substantially impairing the antioxidant systems in the body. Currently, selenium deficiency is incredibly rare in developed countries, but it is projected to become a larger issue as soil becomes depleted of selenium in the coming decades (Jones et al., 2017; Palmer et al., 2011).

### Sodium

Much like potassium, sodium is present in virtually every tissue of the body and is essential for maintaining gradient balance, fluid status, and cardiac rhythm. Where sodium differs from potassium is in its location. Sodium is primarily an extracellular fluid compared to potassium which is primarily an intracellular fluid (Figure: Sodium and Body Tissue).

For comparison, the extracellular concentration of sodium is between 136 and 151 millimolar, whereas potassium is between 3.4 and 5.2 millimolar. Sodium deficiency is virtually unheard of in the developed world, with average intakes of sodium being roughly three to five times the RDA (Institute of Medicine, Board on Population Health and Public Health Practice, Food and Nutrition Board, & Committee on the Consequences of Sodium Reduction in Populations, 2013). Like the micronutrient iron, sodium is well-understood in terms of athletic performance as is the increased need for sodium among athletic populations.

The increased need is primarily due to loss of sodium through sweating (evaporative cooling). Insufficient sodium intake in athletes leads to hyponatraemia, which sets in at concentrations below 135 millimolar. Hyponatraemia can lead to malaise, nausea, cramps, headache, and slurred speech, with extreme cases leading to cardiac arrest and death. While it is well-accepted that many athletes have a higher need for sodium intake than the general population, athlete specific RDIs have not been established.

A diagram of a cell structure

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### Zinc

Zinc provides structure to cells and helps reactions occur. It is the most abundant intracellular of the trace elements and plays regulatory roles in transcription via transcription factors and stabilises nucleic acids. It is also necessary for the creation of tubulin, giving cells their internal rigid structure and allowing them to properly maintain their shape and function. Overt and severe zinc deficiencies are known to cause substantial health issues: alopecia, immune deficiencies, night blindness, delayed wound healing, and growth retardation.

Mild zinc deficiency may lead to impaired growth, which can be corrected through supplementation [(](https://paperpile.com/c/cZDv7y/nZOJa+VDYzz+SVM4d)Hambidge et al., 1979; Sur et al., 2003; Walravens, Hambidge, & Koepfer, 1989[)](https://paperpile.com/c/cZDv7y/nZOJa+VDYzz+SVM4d). Zinc deficiencies range from less than 1% to greater than 25% across the world, with the highest rates of zinc deficiency observed in Sub-Saharan Africa and South Asia [(](https://paperpile.com/c/cZDv7y/1urnv)Wessells & Brown, 2012[)](https://paperpile.com/c/cZDv7y/1urnv). There is also some evidence that high intakes of zinc, especially via supplementation, can result in copper deficiency [(](https://paperpile.com/c/cZDv7y/hSk6t+Pp090+s6n1z)Duncan, Yacoubian, Watson, & Morrison, 2015; Krotkiewski, Gudmundsson, Backström, & Mandroukas, 1982; Lukaski, Bolonchuk, Klevay, Milne, & Sandstead, 1984).

Coach's Corner

Given that zinc does not provide robust, if any, benefits on athletic performance and may result in copper deficiency, zinc supplementation for athletic performance is not recommended.

Getting Technical

In one study, supplementation with 135 milligram of zinc per day for 14 days showed a roughly 15% improvement in peak isometric torque at 180°, but not at any other angle. In a second study, where men were zinc depleted via a low-zinc diet and then repleted, repletion of zinc did not impact aerobic performance (Krotkiewski et al., 1982; Lukaski et al., 1984).

### Common food sources of minerals

Minerals are found in a wide range of foods, coming from both plant and animal sources. Minerals are found in the highest quantities in dairy (e.g., milk, yogurt, eggs, and cheese), beef, shellfish, whole grains, and dark, leafy greens (Figure: Minerals Found in Common Foods).

Food for Thought

Minerals are found in high quantity in beef, shellfish, legumes, nuts, and root vegetables grown in mineral-rich soil. Supplementation is not necessary for minerals in most populations.

A diagram of food allergies

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### Applying knowledge of minerals to the real world

While mineral metabolism is complex, applying this knowledge into the real world can come down to very-basic principles. Ensuring someone obtains adequate minerals in their diet falls in line with the same practical advice for ensuring adequate vitamin intake: consuming a well-balanced diet that is rich in fruits and contains some animal meats or animal by-products.

Furthermore, understanding the varying mineral profiles of different foods and eating a variety of different mineral rich foods can ensure that an individual does not miss key nutrients found in some foods and not others. There are several simple actionable steps that can be taken to help individuals obtain adequate micronutrients.

Use USDA Guideline examples to ensure adequate minerals are ingested:

* Consume three to seven servings of green, leafy vegetables per week.
* Consume fish on a weekly basis.
* Consume three to seven servings of mineral-rich tubers (e.g. potatoes and turnips) per week.
* Consume three to seven servings of legumes and/or whole grains per week.
* Consume three to seven servings of lean cuts of animal meat and/or dairy products per week.

Source: U.S. Department of Agriculture (n.d.). Vitamins and Minerals. National Agriculture Library. Retrieved from <https://www.nal.usda.gov/fnic/vitamins-and-minerals>

These approaches to consuming an adequate amount of minerals falls in line with the USDA guidelines for ensuring the adequate micronutrition discussed.

Try This

Make a list of all the foods that contain water-soluble vitamins, fat-soluble vitamins, and minerals and develop a personal shopping list of foods that are high in all micronutrients and of which foods help clients consume all of them. This can be a weekly grocery list to use with clients.