To conclude our discussion of the nutrients, we will turn to the subject of essential inorganic substances: water and minerals. We seldom think about water as a nutrient, yet it is essential. About 60% of our weight is water, more if we have good muscle density, less if more adipose. Because water is so critical, we shall start our discussion with water.

Water has more functions that we can list:

- Water is the medium in which we transport materials to and from cells and tissues.
- Water is the solvent in which our nutrients function in cells and tissues.
- Water is a participant in hundreds of metabolic processes.
- Water is the medium in which toxic substances are excreted from the kidney. Much of the water lost each day is through the excretion of toxic waste materials.
- Water lubricates and functions as a shock absorber for joints, spinal cord and our eyes.
- Water helps regulate body temperature.
- Water maintains appropriate blood volume.
- Water is needed for digestion. Hydrolysis of polymers requires water.

Water Intake

Most experts say that we need about **two liters** of fluid intake each day, preferably water. Deprived of water, we die within a few days from dehydration and loss of osmotic balance. Important thirst mechanisms exist to help remind us to have fluid intake. When the blood level of water is too low, thirst signals are activated.

- Receptors in the mouth detect dryness from low blood water volume. Signals are sent from the mouth receptors to the hypothalamus.
- Receptors in the hypothalamus of the brain also detect salt concentration in blood.

The hypothalamus initiates the thirst response – as in "I'm thirsty." Unfortunately, the thirst response is a delayed response. Thirst activators respond to existing dehydration. They are great for low-level dehydration, but "fast-acting" dehydration can be serious.

It is also possible to drink too much water. Kidney disorders that affect excretion or ingestion of huge amounts of water can lead to fluid imbalance. Deaths from convulsions have been recorded from water intoxication.

Fluid Intake

Most of us take in about 2.5 liters of water per day, and also lose about that much. Water comes from **liquid intake**, **foods**, especially fruits and vegetables, and from **metabolism**. For example, the products of cell respiration, the oxidation of glucose, are carbon dioxide and water.

Foods that are very low in water, but high in concentrated solutes, can impact fluid intake. Very concentrated sugars, for example, can draw water into the intestine from surrounding tissues, resulting in short-term water loss. Also, substances, such as alcohol, that affect kidney regulation, affect our fluid intake requirement.

Water Losses

We lose water from **kidneys**, **skin** (sweating and wounds), **lungs** (breathing – the lung surfaces must be moist for gas exchange) and **feces**. We need a minimum of 500 milliliters (0.5 liter) of water/day for the kidney to excrete toxic wastes. Average kidney output is between 0.5 and 1.5 liters. Generally a more dilute kidney output is healthier.

The amount we lose from sweating is variable, and can be significant on hot days or when physically active. Sweating is essential for thermoregulation. Loss from respiration and from feces is generally about the same, absent digestive malfunction. Breathing through the mouth can be more dehydrating that through the nose, however, because mucus linings of the nasal passages moisten air.

The kidney's regulatory hormones, discussed previously, respond to water and to salt levels of blood entering the kidney to maintain the appropriate balance. When our fluid intake drops, or losses from sweating from diarrhea increase, kidneys reabsorb more water, and concentrate urine. When water levels of the blood are high, more water is excreted from the kidney.

Water and Minerals

We already know that much of fluid balance in the body is **osmotic balance,** the ratio of water to solutes in the cells and in the intercellular spaces and blood. Osmotic balance is essential for cells to function properly.

We also know that most nutrients, including minerals, are solutes. This means that water must be balanced to the mineral ratios as well as the organic solute ratios of cells and tissues. Mineral balance is therefore critical to water balance. It is not surprising that signals for thirst and hormones that regulate kidney function respond to levels of salts in the blood as well as to water volume.

The amounts of minerals required are nearly constant, so part of osmotic balance is maintaining appropriate mineral concentrations.

In general, minerals are recycled through the small intestine and stomach so that we maintain appropriate blood, and therefore cell, concentrations. The intestinal secretions include minerals. Minerals from food and those secreted are reabsorbed as they pass through the intestines. This helps to maintain appropriate blood levels. The kidneys also excrete excess minerals from blood.

It is important to realize the interconnections of water and minerals in fluids. We rarely lose just water in body fluids; minerals are lost too. This is especially true in sweating, vomiting and diarrhea. Kidney problems and diabetes often result in loss of minerals. Intestinal problems may affect absorption of minerals.

Minerals, Atoms and Ions

Our required **minerals are inorganic ions**. Since ions are charged atoms, and conduct electricity in solution, they are also called **electrolytes**. Minerals must be absorbed and transported to cells and tissues as water-soluble ions. Before we continue our discussion of minerals we might review properties of mineral ions, and how they differ from the organic nutrients.

All matter, which is defined as "stuff", is made up of atoms. Atoms are composed of smaller parts, the three most important are protons, which are positively charged (+), electrons, which are negatively charged (-), and neutrons, which carry no charge. Atoms in the pure state are neutral, because they have the same number of protons as electrons. Neutrons have no affect on the charge of an atom, although they affect the mass of an atom.

Most pure atoms are not stable, however, and need to make bonds with other atoms to become stable. To become stable, some atoms, including minerals, gain or lose electrons, becoming charged **ions**. (An ion is an atom or molecule that is either positively or negatively charged.)

What Are the Minerals?

At last count there were about 20 minerals found in the human body, although not all are considered "essential". Some are so abundant in the foods we eat, and the amount needed so small, that we don’t have to even think about them. We will limit our discussion to those minerals generally recognized as essential, and focus on those which more often may be lacking in diets, or in the case of sodium, getting too much of.

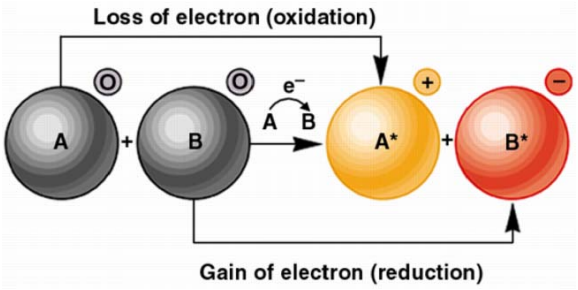
General Functions of Minerals

- **Fluid Balance**
  Potassium, Sodium and chlorine are important minerals in maintaining fluid balance.
- **Structure**
  Minerals are important components of bone and teeth (calcium and phosphorus, fluorine) and some proteins (iron).
- **Hormone Components**
  The metabolic regulator hormone, thyroxin, contains iodine.
- **Metabolism**
  Minerals are essential for nerve transmission and muscle function.
- **Cofactors**
  Some minerals, such as copper and zinc, function as cofactors (inorganic coenzymes) in metabolic reactions

Bioavailability of Minerals

We need an appropriate balance in our cells and tissues of positive (+) and negative (-) ions, along with all of the other essential balances. The need to balance charges is strong, so that many substances bond to ions. Sometimes these bonds make the mineral unavailable, that is, not soluble or usable by our cells. The term used when minerals bond this way is **chelate**. Iron, calcium, copper and zinc are especially prone to chelation by acids in our diet. Because of this, food processing with minerals is very important.

In addition, some ions are easily oxidized (lose electrons) which may change them to insoluble forms. Oxidized iron (Fe^{+++}), for example, is not soluble. The absorbable form of iron is reduced iron (Fe^{++}) since it has one more electron than the oxidized form. Recall that oxidation, the loss of one or more electrons, and reduction, the gain of one or more electrons, are common chemical reactions that are balanced.



Mineral Absorption and Interactions

Some minerals are readily absorbed and transported as free mineral ions. Others must be bound to carriers for transport. Those that are free do not accumulate and are readily excreted. Those that have carriers can accumulate in toxic quantities; those absorbed as free ions are readily excreted, but at a cost of fluid loss.

To complicate things, some minerals enhance absorption of others and some inhibit absorption or promote excretion. Excess phosphorus inhibits absorption of magnesium. Excess sodium promotes excretion of calcium along with the sodium. Potassium is readily excreted whenever there are too many positive ions. Balance of mineral intake is therefore critical. (After a mineral unit you might wonder how you've possible survived to this point without a major deficiency.)

General Comment About Minerals

It seems that, at the completion of mineral discussions, one draws the conclusion that balancing mineral intake may be the most important thing to learn about minerals. Excess intake of one mineral almost always interferes with absorption or utilization of some other mineral(s). It also seems that the best way to ensure sufficient intake of all minerals in balance with one another is to eat a variety of fresh, whole foods. As you look at the charts in your text for mineral food sources, you will see once again the prominence of legumes, whole grains and green vegetables. Organ meats and muscle are often good mineral sources, too, because they are metabolically active body parts. Recall that such foods are often high in fat. Mollusks are high in many minerals, too.

We can now turn to the specific minerals and their functions.

Sodium (Na^+)

Functions

- Sodium helps maintain osmotic balance and pH balance (principal extracellular positive (+) ion, or cation).
- Sodium is the principal solute for water reabsorption in kidney.
- Sodium is needed for nerve transmission and muscle contraction.
- Sodium activates carrier proteins for intestinal absorption.
- Sodium enhances the flavor of many foods.

Recommended Maximum Amount

We should consume no more than 5 - 6 gm/day. We probably need between 100 – 550 mg/day. The recommended **upper limit** for sodium is 2400 mg/day. This makes sodium one of the few essential nutrients for which the recommendation is a maximum, not a minimum.

Most of us consume more sodium than the upper limit. Some cultures may have average consumption of 30 gm/day or more.

Deficiency

- Some kidney diseases promote sodium excretion. This is serious and must be medically attended, since it is a sign of kidney failure.
- Insufficient sodium can induce dizziness and exhaustion. Most short-term deficiency is caused by excessive sweating from extended exercise or heat exposure. Short-term deficiency can also be caused by vomiting and diarrhea.
- Cramping may result from sodium deficiency

  Most of the time, lost sodium can naturally be replaced, along with the water lost by fluid and regular meal intake within a few hours. If the activity was extended over several hours, a dilute beverage that contains a mix of electrolytes can be helpful. (Diluted sports beverage or dilute orange or tomato juice. Concentrated electrolytes aggravate dehydration.

Toxicity

- Edema and hypertension are symptoms of short-term excess sodium. If sufficient water is taken, the kidneys correct the problem.
- Long-term excess salt intake is a factor in hypertension and health. The combination of sodium and chloride in salt is the "culprit".

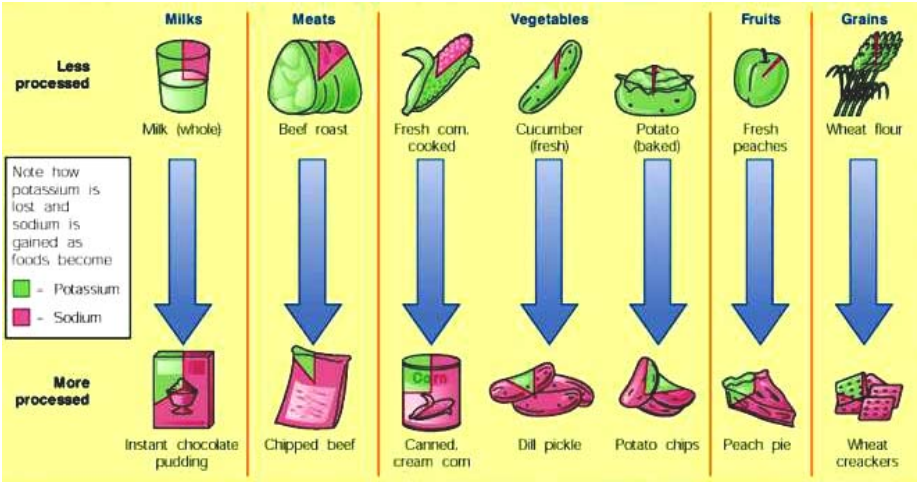
Sodium Sources

- All unprocessed foods naturally contain small amounts of sodium. We get about 10% of our sodium from natural food sources.
- About 75% of our sodium intake is from processed foods Most processed food contains lots of sodium, but you must read labels to determine this. Salty foods, such as chips and pretzels, in which the salt is on the surface often contain less salt per serving than many processed foods where the salt is dissolved in the medium. Soups are particularly high in added salt. Frozen and canned foods typically have added sodium.
- About 15% of our salt intake is from salt we add after food preparation.
    - Virtually every home in the United States has salt shakers on the table and many routinely salt all of their foods before tasting.
    - Some cultures use shoyu or fermented sauces (soy, bean, oyster, etc.) as flavorings. They have significant sodium content.
- Salt is a food preservative.
    - Cured or smoked meats and fish are common.
        - Beef and turkey jerky are sold as snack foods.
        - Hotdogs or Corn dogs top cafeteria sales.
        - Lunchmeats are the foundation of sandwiches.
    - Pickles are a frequent condiment.

Special Considerations

- Much of our sodium intake is **habit**. We enjoy the flavors of foods more with added salt and we are accustomed to foods with lots of salt. It is possible to lower salt intake by changing our eating behaviors, and eating more whole fresh foods. We can also use other flavor enhancers. Anyone who eats mostly processed food will have a very difficult time reducing sodium intake.

- **Processing** of foods, in which salt is added, affects the **potassium** content of foods. Potassium is highly soluble, so processing, particularly processing that involves liquids, results in potassium loss. Fresh foods tend to have the proper sodium – potassium balance. Processed foods have a unhealthy ration of sodium to potassium.



- High sodium intake is associated with **calcium excretion**, but no connection has been made between high sodium intake and osteoporosis. Cultures that have extraordinarily high sodium intakes (up to 30 grams/day) do not have high rates of osteoporosis.

- Some people are salt sensitive. If you are salt sensitive, salt intake increases **hypertension**. People with diabetes or kidney disease, over the age of 50 or African-American heritage are more likely to be salt sensitive. Increasing calcium intake while lowering sodium intake reduces risk of hypertension.

- Obesity exacerbates sodium risks. If you are obese, increase in salt intake increases your risk of heart disease. Salt restriction helps reduce risk, but diets high in vegetables and fruits and weight control are critical.

Potassium (K^+)

Functions

- Potassium is the principal intracellular (+) ion (cation). Potassium maintains osmotic balance for the levels of Sodium found in the intercellular fluid.
- Potassium is needed for insulin release.
- Potassium is essential for nerve transmission. During nerve transmission, sodium floods into the cell to change the relative charge, generating the transmission, Potassium flows out to counter the charge change. Nerve cells then restore resting nerve potential by sodium/potassium pumps. Potassium has similar roles in maintaining proper muscle function.

Recommended Amount

About 2000 mg/day is the recommended minimum. More, when in whole fresh foods is fine.

Deficiency

- Potassium deficiency can occur with dehydration by sweating, vomiting or diarrhea. Potassium leaves cells when body is dehydrated, resulting in an electrolyte imbalance.
- Potassium can also be excreted by the kidney when the overall positive ion concentration in blood is too high. Potassium is highly soluble and more readily leached from the body.
- Diabetics are at some risk for potassium loss with diabetic alkalosis.
- Diuretics, laxatives and some steroid drugs promote potassium loss.
- Low potassium can elevate blood pressure. High potassium lowers blood pressure.

  Muscle weakness occurs when K^+ is chronically low. This can be serious, and cause death from heart failure. Chronic potassium deficiency is common in malnourished children and those with the eating disorder, anorexia nervosa.

Toxicity

- Potassium toxicity from the consumption of fresh foods is unheard of.
- Most excess potassium from supplements or energy drinks will be excreted by the kidneys.
- Potassium injected into the blood can cause heart failure.

Potassium Food Sources

- **Fresh*** fruits, including citrus fruits. Bananas are noted as good potassium sources.
- **Fresh*** cruciferous vegetables, legumes and bright orange vegetables are excellent sources of potassium.
    - ***Potassium readily leaves cells when membranes are destroyed
- Milk products and meats are potassium sources for animal foods.
- As discussed, sodium added to processed foods reverses the normal potassium/sodium ratio, plus potassium is lost in processing methods.

Special Considerations

- High sodium intake forces potassium excretion. Potassium is a more soluble positive ion, and the excretion occurs to minimize ion charge imbalances.
- As stated many times, processed foods are high in sodium and low in potassium. Consumption of fresh foods improves the body's sodium/potassium balance.

Chlorine (Cl^-)

Form

Chloride ion (Cl^-)

Functions

- Chlorine in the primary (-) ion (anion) in the body, used to balance sodium (+) in extracellular fluids and potassium (+) in intracellular fluids.
- Chlorine is important for pH, electrolyte and fluid balance.
- Chlorine is a component of hydrochloric acid (HCl) in the stomach.
- Chlorine helps to move carbon dioxide from blood into the lungs for excretion.

Recommended Amount

- An estimated minimum amount for adults is 500 mg/day. Chlorine is abundant in foods, associated with sodium and other salts.

Deficiency

- Chlorine deficiencies are not heard of under normal health conditions.
- A chlorine deficiency can be found in infants fed very low salt formulas.

Toxicity

- Excess chlorine is excreted from the kidney.
- Severe dehydration from in sufficient water intake can cause an increase in blood chlorine levels. Chlorine balance is restored as soon as normal water intake is restored along with consumption of foods.

Sources of Chlorine

- Whole foods naturally contain some chlorine.
- Processed foods contain significant chlorine because the added salt is NaCl.
- All salts and salt substitutes contain chlorine. The most common salt substitute is potassium chloride (KCl)
- Chlorine (not chloride) is a toxic gas. Chlorine is added to public water supplies to destroy bacteria and some protist pathogens. The dissolved chlorine evaporates, but some chloride ions remain in drinking water.

Special Considerations

- When losses of hydrochloric acid are high, generally from serious and prolonged or chronic vomiting, blood plasma gains too much bicarbonate, the buffer used to neutralize H^+ ions reabsorbed into the plasma from gastric secretions. Loss of HCl means fewer H^+ ions get reabsorbed. Metabolic alkalosis can result from the pH imbalance.

Calcium (Ca^{++})

Functions

- Calcium is the primary mineral constituent of **bone** and of teeth.
- Calcium is also found in blood and cytoplasm. Calcium in **metabolism** is needed for:
  - muscle contraction. (Calcium in the sarcoplasmic reticulum responds to the neuromuscular synaptic transmission to activate contraction. Calcium is then returned to the sarcoplasmic reticulum for muscle relaxation.)
  - synaptic transmission of nerve cells
  - activation of signal transduction pathways in cell metabolism. (Calcium is a secondary messenger within the cytoplasm of the cell, and a component of **calmodulin**, a signal molecule activator.)
  - blood clotting
  - cofactor for many enzymes
  - neutralizing bile acids in the colon.

Recommended Amounts

- Adolescent recommendation is 1300mg/day in the United States
- 1000 mg/day is recommended for adults up to age 50.
- Adults over 50 should have 1200 mg/day and for women at risk for osteoporosis, 1500 mg/day. That's a lot of calcium.

Storage

- Bone calcium serves as the calcium reservoir for blood calcium

Food Sources

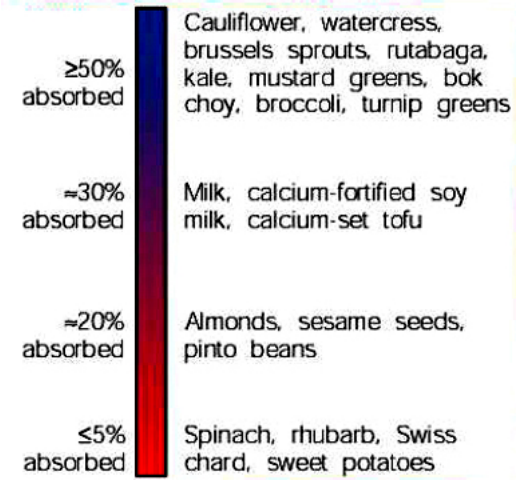
The best food sources of calcium are:

- Bony fishes, especially canned fishes — 3 oz = 300 mg
- Tofu (from processing) — 4 oz = 150 mg
- Legumes — 3/4 cup = 50 mg
- Broccoli — 1 cup = 200 mg
  - Other Cruciferous vegetables are also good sources of calcium
- Non-fat milk or yogurt — 1 cup = 300 mg
- Cheese (except cottage cheese) — 1 oz = 200 - 300 mg

- Calcium is also found in black strap molasses, nori, almonds and sesame seeds
- Some bottled waters have calcium, too.

Calcium Absorption

Calcium requires a binding protein for absorption. We generally absorb about 30% of ingested calcium, but the amount is variable, depending on the food source and a number of factors that either promote absorption or inhibit absorption.



Absorption is promoted by:

- Stomach acid and Vitamin C, which maintain calcium in an absorbable form
- Lactose
- Phosphorus
- Vitamin D (because it is needed to synthesize the binding protein) More binding protein is manufactured when more calcium is needed.
- Low levels of dietary calcium promote more efficient absorption.
- Physical exercise may increase the body's ability to absorb Calcium

Calcium absorption is inhibited by:

- Inadequate Vitamin D
- High phosphorus intake relative to calcium intake
- Inadequate stomach acid to keep calcium in an absorbable form
- The chelating acids found in high-fiber foods bind calcium, but the level of fiber consumed by most people in the United States has minimally affects calcium absorption. The chelating acids are:
    - Phytic acid
        - Binds Ca^{++}, Fe^{++} and Zinc
        - Found in whole grains, seeds and nuts
    - Oxalic acid
        - Binds Ca^{++} and Fe^{++}
        - Found in many dark green vegies, but is particularly abundant in the Chenopodiaceae foods (spinach, chard, rhubarb)
    - Uronic acid (in grains)
        - Binds Ca^{++}
        - Found in whole grains

The Calcium Bone - Blood Balance: Calcium Homeostasis

It is essential to maintain appropriate blood levels of calcium. To do so, the body constantly monitors Ca^{++} in the blood and has a number of ways to either increase levels or decrease levels as appropriate involving hormones and vitamin D.

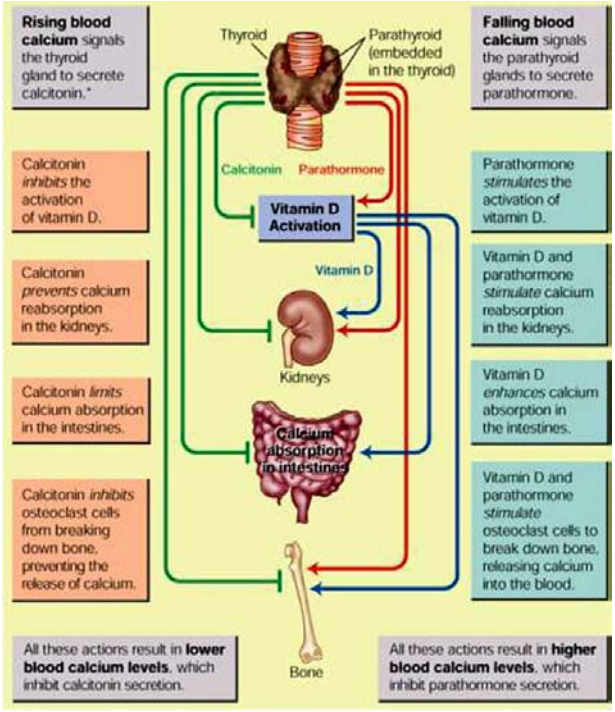
If blood calcium levels are low, the hormone parathormone, promotes Vitamin D synthesis and activity.

- The production of calcium binding protein increases, promoting absorption of calcium from the intestine. Vitamin D is needed for the binding protein synthesis.
- Vitamin D and parathormone promote reabsorption of calcium from the kidneys.
- Vitamin D and parathormone promote release of calcium from bone cells if blood levels remain low.

If blood calcium levels are too high, the hormone calcitonin inhibits vitamin D activity preventing or reducing:

- Calcium reabsorption from the kidneys
- Calcium absorption from the intestines
- Calcium removal from bone cells

If blood calcium levels are not in balance, muscle contraction is affected. If too high, muscles contract but don't relax, a condition of calcium rigor. If too low, muscles go into tetany, where muscle contraction is constant and uncontrolled. The effect is the same. It's important to understand that calcium imbalance in blood is caused by regulator problems, not by too much or too little dietary calcium. The body always keeps a balance of blood calcium by taking calcium from bones when intake is too low.

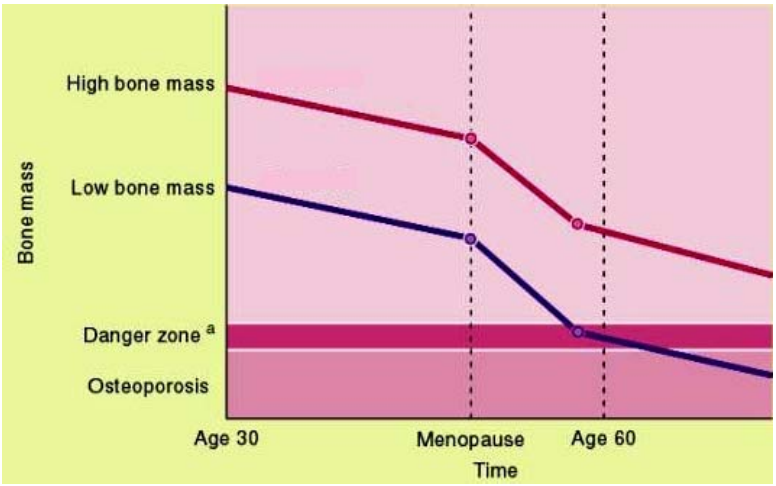


Deficiency
Since blood levels of calcium are kept constant, regulated by hormones and vitamin D, calcium deficient diets, or diets lacking in those substances required for calcium absorption, affect the calcium level of **bone.** Excessive calcium loss in bone leads to **osteoporosis.**

Toxicity
Too much calcium can result in excess deposition of calcium in bone.

Bone Formation, Bone Loss and Osteoporosis
When bone forms, calcium phosphate crystallizes on a collagen matrix within the bone tissue. As the crystals become denser, bone strengthens and becomes rigid. Bone gains and loses minerals constantly. During growth, long bones degrade and are rebuilt as they lengthen. If more minerals are removed than added back, bones weaken and become fragile. The mineral fluorine is needed to harden calcium deposits.

After about age of 30, it's difficult to increase bone density, but losses, which can lead to osteoporosis, readily occur, particularly in women after menopause. It's critical to maximize bone strength when young by maintaining appropriate calcium intakes.



Minimizing Risk of Osteoporosis
The best way to minimize one's risk of osteoporosis is to have adequate intake of calcium during one's growth years, up to the 30's, when bones can gain density.

Factors in Maintaining Bone density Include:

- As one ages, calcium is absorbed more poorly and vitamin D is less available to help in calcium absorption. Both calcium and vitamin D intakes need to increase when one gets older to counter this.
- Physical activity that puts "stress" on weight-bearing bones helps maintain bone strength and density. In addition, more body weight puts stress on bones, and results in more bone density. Weight loss can reduce bone strength. Underweight people are more likely to have lower bone density. Anorectics are at serious risk for osteoporosis.
- Smoking affects bone density and promotes bone degeneration.
- Excessive alcohol use promotes excretion of electrolytes, including calcium, through the kidneys. Alcohol also negatively influences hormones needed for bone maintenance
- Being male reduces the risk of bone loss because males generally have denser bones. However, males are not risk free. Older men suffer debilitating fractures just as older women do. Testosterone may also be bone calcium protective.
- Estrogen protects bones from calcium loss. The rate of bone loss in menopause accelerates unless measures are taken to prevent excessive loss. Hormone replacement retains bone calcium. Unfortunately, for many women, the risk of cardiovascular disease and some cancers increase with estrogen/progesterone supplements. Estrogen supplements alone increase the risk of endometrial cancers in women who have intact uteruses. Phytosterols that mimic estrogens may have some benefit in preventing bone loss, but they may also mimic the cancer promoting effects of animal estrogens.
- There are some prescription drugs, notably **fosamex**, that minimize bone loss and can, to some extent, reverse bone calcium loss. All drugs have side effects, and use should be discussed with one's physician.
- Genetic heritage may play a role in the tendency towards osteoporosis. Those of northern European heritage are at greatest risk for osteoporosis. Osteoporosis is less common in those of Asian or Hispanic heritage, even when bones are not particularly dense.
- Osteoporosis is not common in ethnic groups who do not drink milk or use many dairy products. They have much lower intakes of calcium throughout life, yet maintain calcium blood balances well and have excellent absorption of calcium. It makes one think that bodies habituate to higher calcium levels in foods with less efficient absorption, and declining calcium intake and absorption leads to blood/bone imbalances over time.

Special Calcium Considerations

- Increasing calcium in the diet while lowering sodium may reduce hypertension risks.
- Antacids that contain magnesium or aluminum can accelerate calcium losses. Antacids that contain $CaCO_3$ (Calcium carbonate) provide calcium.
- **Calcium Supplements and Fortification**
    - To maximize absorption of supplements, the calcium in the supplement should be bonded to an organic acid
    - The amount of calcium in the supplement varies; no matter what, it's bulky, so you need to take a lot of them to get the daily requirement. Some calcium supplements are inorganic. The inorganic supplements can have heavy metal contaminants, depending on the source, and are less absorbable than the organic calcium sources. Some examples are:
        - Oyster shell $CaCO_3$
        - Dolomite
        - Bone meal
    - Calcium supplements with added vitamin D or magnesium are often recommended, since both vitamin D and magnesium are beneficial in calcium metabolism. However, too much vitamin D in supplements added to the vitamin D consumed in dairy products can result in toxic levels of vitamin D.
    - Some Calcium supplements contain substances that inhibit uptake of iron or magnesium, involving different risks.
    - People who are prone to kidney stones need to restrict calcium intake in the form of the more soluble supplements.
    - Food sources of calcium apparently do not have negative interactions in the way supplements do.
    - Some foods are available fortified with calcium, such as:
        - Milk
        - Some cereals
        - Orange juice
        - Chocolate chews

Phosphorus (P) (Usually as Phosphate, $PO4^{---}$)

Functions

- Most of the phosphorus in the body is found in the bone crystals of calcium phosphate, needed for bone strength.
- Free phosphate ions are found in the cytoplasm of all cells
- Phosphorus is a component of
    - ATP
    - DNA and RNA our genetic molecules
    - Phospholipids
    - Some neurotransmitters
    - Blood buffers (as phosphoric acid)
- Phosphate donated from ATP is needed for activating many B vitamins

Recommended Amount

- Adults need about 700 mg/day
- Children need almost twice as much phosphorus as adults.

Food Sources

Most diets have adequate phosphorus, in part because foods we eat for energy (calories) and foods rich in protein are good sources of phosphorus. Some of the best sources are:

- Meat, poultry and fish
- Legumes
- Milk, which also has a good calcium/phosphorus balance
- Phosphoric acid containing carbonated beverages
- All whole food has some phosphorus.

Deficiency

Phosphorus deficiency is rare but bone demineralization can occur with individuals who have eating disorders such as anorexia, or with starvation.

Special Considerations

Some antacids can inhibit phosphorus absorption.

Magnesium (Mg^{++})

Functions

- Magnesium functions as a cofactor for **hundreds** of enzymes including the use of fuel molecules in metabolism.
- Magnesium is needed for ATP synthesis
- Magnesium functions in preventing blood "over clotting"
- Magnesium is needed for muscle relaxation and prevents muscle spasms of the heart and arteries.
- Magnesium affects the metabolism of calcium, potassium and Vitamin D and helps keep calcium in teeth.
- Magnesium is a component of chlorophyll, the molecule that absorbs light energy for the process of photosynthesis. (OK, this is not a human function, but without photosynthesis, there would not be life on earth as we know it.)

Recommended Amount

- The magnesium recommendations are set at 320mg/day for women and 420 mg/day for men.
- We rarely get sufficient magnesium in our diets.

Storage

Bone is the reservoir for magnesium, and like calcium, bone reserves are used to maintain blood levels as appropriate.

Food Sources

- Anything with chlorophyll (dark green leafies)
- Nuts and seeds
- Legumes
- Whole grains
- Chocolate (It's derived from the seeds of the chocolate tree.)
- Some drinking water, especially if it is mineral-rich hard water, contains magnesium. The Seattle area water supplies are not magnesium rich.

Deficiency

- Although intakes are below recommended levels, deficiency is rare, except for protein malnutrition associated diseases and alcoholism. Prolonged vomiting, diarrhea or diuretics that remove magnesium with fluid losses can cause deficiency symptoms.
- Magnesium deficiency symptoms include muscle spasms, or tetany, especially of the arteries. Uncontrolled muscle twitches are common.
- Magnesium deficiency is suspected in alcoholic hallucinations during periods of withdrawal

Magnesium Toxicity

- Toxicity can be induced with excessive intake of supplements and can cause dehydration from diarrhea.
- Excessive intake of chocolate is not known to cause magnesium toxicity.

Special Considerations

- Magnesium may protect against hypertension, particularly in preventing constriction of arterial walls. When magnesium levels are low, arteries tend to constrict more, resulting in hypertension.
- Alcohol inhibits the absorption of magnesium and alcoholics exhibit magnesium deficiency symptoms.
- Oxalic and phytic acids inhibit absorption of magnesium.

Sulfur (S)

Functions

- Sulfur is a component of the amino acids cysteine and methionine, but we take in these amino acids. We do not synthesize them.
- Sulfur is a component of thiamin, biotin, lipoic acid and pantothenic acid, but it doesn't matter too much since, except for lipoic acid, these are essential dietary substances
- Sulfur promotes some metabolic activities, such as:
    - Collagen synthesis
    - Liver detoxification
    - Blood clotting

Recommended Amount

- There is no sulfur recommendation since the need for sulfur is met by the need for amino acids and the vitamins for which is a structural component.

Food Sources

- Any food containing protein provides sulfur in the diet. We eat more than enough protein.

Deficiency

- Those who have protein malnutrition will suffer symptoms of protein malnutrition, not sulfur deficiency.

Toxicity

- Sulfur toxicity is not known.

Iron (Fe^{++} or Fe^{+++})

Forms

Iron is found in two forms, reduced and oxidized.

- Ferrous (Fe^{++}) reduced iron, which is soluble
- Ferric (Fe^{+++}), oxidized iron, which is not soluble

About 80% of the iron in the body is found in blood, being recycled from the breakdown of red blood cells to bone marrow for manufacture of new red blood cells.

Functions

- Iron is a component of many proteins such as:
  - Hemoglobin: Iron binds to oxygen
  - Myoglobin: Oxygen binder in muscle tissue (darker muscle = more myoglobin)
  - Cytochromes: Energy transfer molecules in cell respiration
- Iron is a cofactor for neurotransmitters in the brain and for many oxidizing enzymes because it can gain and lose electrons between its two forms.

Recommended Amount

- About 8 mg/day for males and post-menopause females
- About 18 mg/day for females until menopause

- Often diets are lacking in sufficient iron, while some very active males who consume many calories of enriched grains may be getting too much iron.

Storage

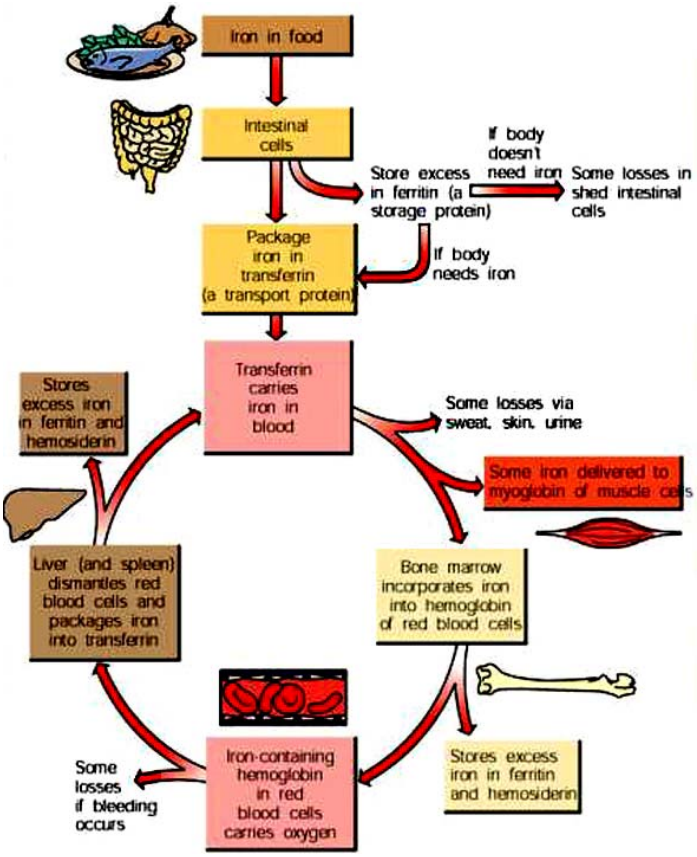
- Excess iron is stored in bone marrow and in the liver and spleen

Food Sources of Iron

- Good Absorption
  Muscle tissue, dark organ meats and some mollusks
- Low Absorption (10%)
  Eggs, most dry legumes, grains (many are enriched with iron) and nuts
- Very Low Absorption (2%)
  Leafy greens and iron supplements.
- Some fruits, such as apricots and raisins and figs contain iron.
- In addition, cooking in iron skillets can provide a small amounts of oxidized iron, especially when acid foods are prepared in the skillet.

Availability and Absorption of Iron

Intestinal proteins, called transferrins, are needed to carry iron from the intestine into the blood. Excess ingested iron is held in reserve in the intestinal mucosa, and shed with those cells if not absorbed. Blood levels of iron determine the efficiency of absorption. It's difficult to determine iron absorption because of individual adaptations to levels of iron reserves and also iron in the diet. As with some other minerals, those whose diets are chronically low in iron seem to be more efficient at absorbing iron. Genetics is also important. Some are genetically prone to absorbing and storing excess iron, a condition known as hemochromatosis.



The ability to absorb iron also depends on its source. Iron bound to muscle protein, called heme iron, is far more absorbable than non-heme iron, common in plant foods and non-muscle animal foods. Only about 10% of non-heme iron is absorbed, while 25% of heme iron can be absorbed.

Things that **promote absorption** of non-heme iron include:

- Iron in its reduced form (Fe^{++}). Most supplements and fortified iron sources contain reduced iron.
- Vitamin C, which keeps iron in the reduced state. Acids in general aid iron absorption, except those that chelate it.
- The MPF factor found in muscle tissue promotes absorption of non-heme iron.
- Alcohol promotes iron uptake. Red wine contains iron. Alcoholics can be at risk for iron toxicity.

Iron absorption is inhibited by:

- Phytic acid in whole grains (Yeast degrades phytates)
- Oxalates
- High calcium/phosphorus (as in milk)
- Tannins (found in many nuts)
- EDTA in food additives
- High body stores of iron

Deficiency

The most common long-term iron deficiency symptom is **anemia**; low levels of iron prevent synthesis of hemoglobin, needed carry oxygen on red blood cells.

- Worldwide, more people are deficient in iron than in any other nutrient. About one-third of the world's women and children have iron deficiency anemia.
- About 10% of the United States children, women of child-bearing age and the elderly are deficient in iron. Iron deficiency is centered in poverty areas.
- Short-term deficiency occurs whenever there is significant blood loss.
- Women require more iron then men because iron is lost during menstruation
- Pregnant women require additional iron, and are more likely to be deficient.
- Intestinal parasites and intestinal disorders can result in poor absorption of iron, and iron deficiency.

Deficiency Problems

- Anemia causes fatigue, weakness, headache, apathy and depression.
- Iron deficiency impairs cell respiration, so it's harder to do physical activity.
- Productivity lessens. Children don't learn as well, because they are tired and weak.
- Iron deficiency can result in strange "food" cravings called PICA. Ice, clay, paste, etc. are common cravings.
- Some children can have brain damage and psychological disorders from iron deficiency.
- Iron deficiency impairs temperature regulation. Low levels of iron may result in not being able to feel warm.

Iron Toxicity

- For many, iron toxicity is rare because the intestinal transferrins limit absorption of excess iron.
- For those with **hemochromatosis,** a genetic disorder in which iron is readily absorbed and stored, toxicity can lead to weakness, headache, liver disease, diabetes, arthritis, increased bacterial infections and heart failure. Men are at greater risk for symptoms of hemochromatosis because they need less iron and consume more calories, including enriched grain products, such as bread and pasta, that contain iron. Unfortunately, hemochromatosis is a common genetic problem.
- Chronic excess supplement taking can also lead to iron overload when iron intake "overwhelms" the intestinal cells' ability to regulate absorption. When vitamin C supplements are taken along with iron, it is more likely to result in toxicity, because vitamin C frees iron from ferritin, so iron can become a free radical.
- Blood transfusions can also cause iron overload.
- Free iron levels may affect health. Free iron can oxidize LDL, a factor in cardiovascular disease. Those with lower levels of iron in blood seem to be at lower risk of cardiovascular disease, but documentation is weak.
- The free radical effect of iron can also have a role in cancers, although no specific iron link to cancer has yet been identified.
- Children may have fatal iron poisoning from taking iron supplements. As little as 200 mg can be fatal. (This is the #2 cause of children's poisoning after aspirin.) Symptoms of iron poisoning include vomiting and diarrhea, nausea, rapid heartbeat, respiratory distress, shock and confusion. The iron kills cells through free radical damage.

Special Note

People, especially women, who consume lots of dairy products may not get enough iron. Milk has virtually no iron and contains high levels of phosphorus and calcium that inhibit iron absorption. In addition, when one is sedentary, the total calories consumed must be restricted, and after the dairy product calories, there may not be enough calories left for iron-rich foods.

Zinc (Zn^{++})

Functions

- Zinc is a cofactor for **dozens** of enzymes, including the digestive enzymes
- Zinc is needed for synthesis and release of insulin in the pancreas
- Zinc is needed for immune system function
- Zinc is necessary for activation of the visual form of vitamin A and vitamin A transport
- Zinc is needed for protein synthesis
- Zinc influences learning and behavior, affecting nervous system function.

Recommended Amount

About 8 mg/day is recommended for women and 11 mg/day for men. Children need more.

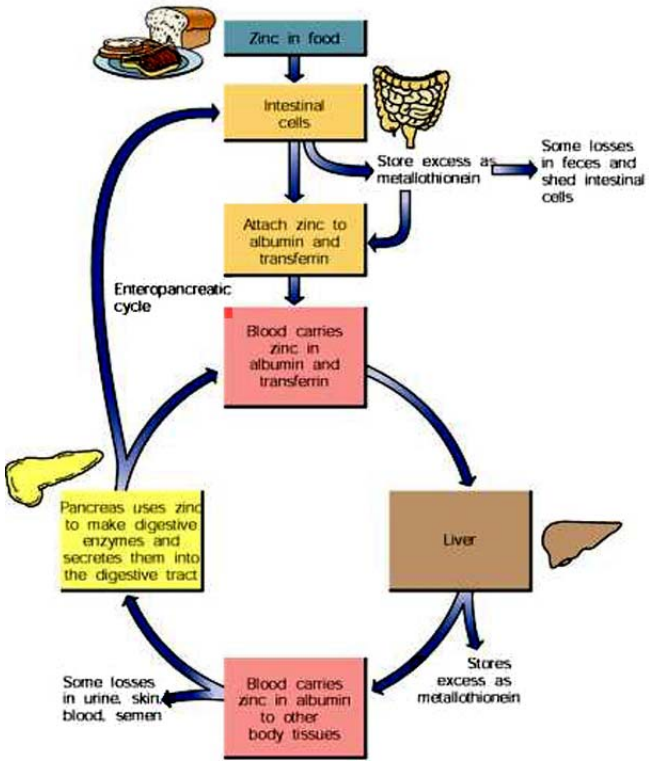
Food Sources

- Mollusks, especially oysters, are very rich in zinc
- Muscle and organ meats contain zinc
- Large quantities of legumes and whole grains provide zinc, but also contain zinc-binding phytates. We generally eat too little fiber-rich foods to have an affect on zinc, however. If one has a very high fiber diet, more zinc would be required.
- The amount of zinc in most vegetables depends on the zinc content of the soil in which they were grown. None are exceptionally good sources.
- Milk products have some zinc.

- Zinc in digestive enzymes is also available for absorption and recycling.

Zinc Absorption and Availability

Absorption of zinc varies from almost none to about 40% depending on body reserves. A protein metallothionein is needed to bind to zinc in the intestinal cells. If little zinc is in the intestinal cells, more is absorbed from foods digested. Metallothionein is transported from the intestinal cells to the liver. In the liver, zinc is freed from the metallothionein as needed and rebound to albumin and transferrins for general circulation. Excess zinc is not absorbed and removed with feces.



Deficiency

- Zinc deficiency symptoms show first in growing children. Enzymes involved in growth don't function without zinc and growth retardation results.
- Digestion is affected because the zinc-containing hydrolytic enzymes aren't available and diarrhea is common.
- The immune system is impaired so wounds heal poorly and infections are common.
- Vitamin A is not synthesized, so symptoms of vitamin A deficiency also appear.
- Chronic deficiency can lead to nerve and brain damage with poor motor development and processing skills.

Toxicity

- Excess zinc intake causes vomiting, diarrhea, headaches and exhaustion.
- Excess zinc intake may accelerate development of artherosclerosis

Special Considerations for Zinc

- The popularity of zinc supplements for alleviating and shortening the duration of colds can lead to short-term toxicity. The only form of zinc that has been shown to help colds is **zinc gluconate**. It leaves a metallic aftertaste in the mouth. Flavoring agents added to the gluconate interfere with zinc absorption.
- Zinc can bind to transferrin, the molecule that carries iron, and excesses of zinc can interfere with iron transport. Similarly, iron overload can interfere with zinc absorption and transport.
- Zinc and copper compete for binding sites on intestinal cell membranes and both bind to the intestinal cell metallothionein. When zinc intake is high, more metallothionein is synthesized. Metallothionein binds more tightly to copper and prevents absorption of copper. Intake of zinc out of proportion to intake of copper can inhibit copper absorption.
- Infections often decrease albumins, so zinc is distributed less well. In addition, zinc's role in the immune system function is compromised.
- Free dietary amino acids bind zinc (a reason not to take amino acid supplements?)
- Flukes and other parasites often reduce zinc levels
- Heavy metal contaminants can inhibit zinc absorption and zinc's cofactor function. They can compete for the cofactor site on the enzyme.
- Yeast organisms digest phytates, so leavened breads have more zinc available that non-leavened breads.

The Lesser Known or Trace Minerals

There are a number of additional mineral nutrients, needed in small quantities, some of which are not as well known, or as well studied. For some, the amount we need is related to the soils in which plants are grown, or animals raised that feed on the plants. For example, selenium deficiency shows up in one region of China where soils are deficient. Historically, iodine deficiency was common in regions where soils were lacking in iodine. For some of these minerals, it takes very little additional intake to have toxicity symptoms, so supplements are generally not recommended. In addition, as we have seen with some of the other minerals, high intake of one mineral interferes with use of or availability of others. It's best to have a variety of whole fresh foods, the combination of which ensures that we get our trace minerals. A few things will be noted about some of the trace minerals.

Iodine (I^-) (Iodide in cells and tissues)

Function

Iodine is a component of **thyroxin,** the hormone that sets the basal metabolic rate of the body by controlling the rate at which oxygen is consumed by cells.

Recommended Amount

We need about 150 µg/day of iodine.

Sources

- Foods taken from the ocean contain iodine.
- Vegetables from soils that are iodine rich (Puget Sound soil is not)
- Milk contains iodine if the dairy cows feed comes from iodine-rich soil.
- Some dough conditioners contain iodates.
- Iodized salt is a primary source of iodine in the United States.

Deficiency

- When iodine is not available, the thyroid gland enlarges causing goiter. Goiter is caused by excessive growth of thyroid tissue in the body's attempt to produce thyroxin. The hypothalamus secretes the thyroid stimulating hormone in response to low thyroxin levels. Goiter affects about 200 million people world-wide. Goiter has been virtually eliminated in North America since iodized salt became available in the 1930's.
- Deficiency of iodine results in lowered basal metabolism, a sense of tiredness and often, weight gain. (Cell respiration rate is affected, so fewer calories are metabolized.)
- Iodine deficiency in fetal development results in growth and mental retardation called cretinism.

  It should be noted that hypothyroidism can be caused by a number of things, not just iodine deficiency. Radiation poisoning is a common cause of thyroid problems. Radioactive iodine is common in radiation emissions. In the 1950's it was common to use radiation to reduce thymus gland tissue in children. As adults, many have thyroid problems.

Iodine Toxicity

- The upper level for iodine intake is 1000 mg/day. Too much iodine stimulates the thyroid tissue to produce goiter, as well. Toxic levels of iodine taken during pregnancy can cause fetal goiter sufficient to inhibit breathing in the newborn infant. Thyroid enlargement, which may inhibit breathing

Special Considerations

- Most people in the United States consume too much iodine because we consume too much salt.
- Cabbage family foods have iodine antagonists, called goitrogens. If the foundation of one's diet is cabbage family foods, it is possible to get goiter if iodine intake is low. Over consumption of cabbage family foods, in combination with too little iodine, is virtually unheard of in the United States. It does happen in other parts of the world.
- Iodine is sometimes used as a disinfectant. When dairy farmers use iodine, cattle can inadvertently get more iodine, and their milk will contain more iodine. Iodine in most forms is not recommended as an antiseptic since it harms tissue surrounding the wound. A form, called **betadine**, is used as a topical disinfectant to destroy bacteria prior to some surgeries.

Selenium

Functions

- Selenium is a component of the enzyme, **glutathione peroxidase**, that inhibits free radical formation. Selenium works in tandem with vitamin E. Vitamin E stops free radical chain reactions when selenium can't catch them. Protection of polyunsaturated fatty acids is an important job of selenium.
- Selenium is also involved in converting thyroxin to its active form.

Recommended Amount

- The RDA for selenium is set at 55 µg/day.

Food Sources

Selenium is found in any plant foods grown in soils containing selenium or animal foods from animals who ate plants grown in soils containing selenium. Most soils contain adequate amounts of selenium, and most of us eat foods transported from all areas of the world.

Deficiency

Kesham disease, a specific selenium deficient heart disease, is prevalent in one area of China because the soil is deficient in selenium. Kesham disease is actually caused by a virus, but low selenium predisposes susceptibility to the virus.

Some cancers are more common in areas of the world that are selenium poor. The connection is not understood, and whether added selenium would prevent the cancers is not known yet.

Patients fed intravenously for long periods can exhibit selenium deficiency

Toxicity

- Selenium intakes of about 1 mg cause toxicity. This amount of selenium is unheard of except when people take supplements.
- Toxicity symptoms include:
    - Keratin loss, including hair loss and nail loss
    - Diarrhea and vomiting
    - Skin and nerve lesions

Copper (Cu^{+} - insoluble, Cu^{++} – soluble)

Function

- Copper is a component of many enzymes that involve reactions with oxygen, including the cytochromes of cell respiration.
- Copper helps to keep iron in the form needed for hemoglobin synthesis.
- The copper containing enzyme, superoxide dismutase, helps control free radicals.
- Other copper-containing enzymes cause oxidation reactions by getting reduced. (In that sense, it's sort of an anti-reductant, although that term is not used.)
- Copper works cooperatively with zinc, but unbalanced intake of either interferes with the other. Zinc, copper and iron all share transferrin carriers.

Recommended Amount

- Adults need about 900 µg/day. The upper limit has been set at 10 mg.

Deficiency

- Copper deficiency can occur with protein deficiency in children, and results in anemia.
- High vitamin C intake can also cause a copper deficiency by inhibiting absorption.
- Animal studies show that copper deficiency can cause elevated serum cholesterol and accompanying artherosclerosis.
- A very rare genetic disorder, Menkes disease, prevents intestinal cells from releasing absorbed copper into circulation, a disorder that is life-threatening.

Toxicity

- Excess copper is eliminated from the liver in bile, but is subject to reabsorption.
- Copper toxicity naturally is very rare, but can cause vomiting and diarrhea.
- The genetic disorder, Wilson's disease, causes copper to accumulate in liver and brain tissue, and can be fatal. Drugs that inhibit copper absorption, zinc supplements and copper chelating agents can all be used to treat Wilson's disease.

Copper Sources

- Copper is found in:
    - Legumes
    - Whole grains
    - Shellfish (Crustaceans and Mollusks)
    - Organ meats
    - Seeds
- Copper is also in some water supplies and some leaches from copper plumbing.

Manganese

Function

- Manganese functions as a cofactor. (How surprising)

Recommended Amount

- Women need about 1.8 mg and men about 2.3 mg/day

Deficiency

- Manganese deficiency is exceedingly rare, because the requirement is low and many foods contain generous amounts of manganese.
- If one were to have a manganese deficiency, fat metabolism would be affected, because manganese is involved in fat oxidations.

Toxicity

- Manganese dust can cause problems for miners, including facial abnormalities, speech problems, loss of muscle coordination and brain dysfunction.

Manganese Sources

- Whole grains, legumes and leafy vegetables are the best sources of manganese.

Special Considerations

- Iron and calcium may inhibit manganese absorption, so those who take supplements need to be sure they have adequate intakes of foods that are good manganese sources.
- Phytates chelate manganese.

Fluoride (F^-) (Fluorine)

Function

- Fluoride is essential for strong teeth and strong bones. Fluoride hardens the calcium crystals. Teeth with adequate fluoride are resistant to decay, and bones are stronger.

Recommended Amount

- Intake for women is 3.1 mg/day and men, 3.8 mg. Up to 10 mg/day is safe.

Deficiency

Lack of fluoride is the primary cause of tooth decay. People without teeth have many nutritional problems, both because food isn't chewed as well, and because wholesome foods are avoided because they are difficult to chew. Diseased teeth are painful and prone to infection. Fluoride toothpastes became available in the 1950's and communities started fluoridating water supplies about the same time. It made a miraculous difference in dental health. Fluoridation of water of 1 ppm is adequate.

Excess Intake

An excess of fluorine can result in darkened and pitted teeth, called **fluorosis**. The teeth are exceptionally strong, however, and tooth decay is unheard of.

Toxicity

20 - 80 mg/day may result in halide toxicity. If water is accidentally overdosed, 150 ppm can cause nausea and vomiting along with numbness and tingling of the arms, legs and face.

Sources

- More than 50% of the people in the United States obtain their needed fluoride by consuming fluoridated water and using fluoride toothpaste. Swallowing toothpaste is not recommended, and the amount of toothpaste used by small children should be monitored.
- Some soils are fluorine rich, and plants grown in those soils contain fluorine. Fluorine-rich soils are rare, but these are the areas where fluorosis is more likely to occur.
- Ocean food sources contain some fluoride.
- Tea, although not herbal tea, often contains some fluoride.

Special Considerations

There are often campaigns to remove fluorine from water supplies contending the fluorine is a poison and communities are poisoning us by adding fluorine to water. The same concerns are sometimes raised about chlorine and about iodine. In fact, all of the halides are toxic in concentration, and with everything, we need to take into perspective what we are doing. Fluorine is an essential nutrient that is almost impossible to obtain in the natural foods we eat. Adding an appropriate amount to water ensures healthy teeth and healthy bones, which improves health for millions; it does not poison us.

Chromium (Cr^{+++})

Function

- Chromium is needed for insulin to promote glucose uptake by cells. Absence of chromium in the diet induces diabetes-like symptoms.

Absorption

- When chromium is complexed to a small organic molecule, called the Glucose Tolerance Factor, absorption of chromium is improved.

Recommended Amount

- Women need 25 µg/day and men need 35 µg/day

Sources

Chromium is present in many foods. Some good sources are:

- Nutritional yeast (a very yucky food)
- Liver
- Whole grains
- Cheese
- Nuts

Special Considerations

- Chromium is easily lost with food processing. Refined grain products are not enriched with chromium.
- Chromium picolinate supplements are widely marketed for improving muscle strength and ease of building muscle and losing fat particularly for those doing weight training. The efficacy of the supplements is questionable. Longer term studies have not shown benefits.

Molybdenum

Function

- Molybdenum is a component of flavinprotein, an energy transfer carrier of the respiratory chain, derived from riboflavin.
- Molybdenum is also a cofactor of some metalloenzymes.

Recommended Amount

- Adults need about 45 µg/day.

Food Sources

Good food sources of molybdenum include:

- Legumes
- Grains
- Organ meats
- Leafy greens

Deficiency

Molybdenum deficiency is unknown, in part because we need so little of it.

Toxicity

If by accidental poisoning, or if induced, a molybdenum toxicity may produce gout-like symptoms and kidney damage. Molybdenum as a mining by-product, if inhaled, can be toxic.

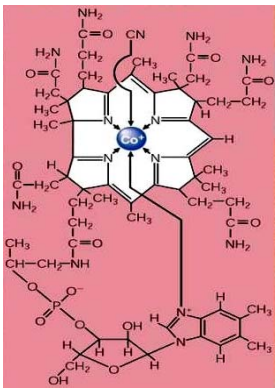
More Minerals

Boron

Boron is needed to maintain bone, and possibly brain, tissue

Cobalt

Cobalt is a component of Vitamin B_{12} However, we can not manufacture Vitamin B_{12} from cobalt, so we have no requirement for cobalt.



Nickel

Nickel may be needed to maintain tissues in some way, functioning as a cofactor. Liver damage can result with nickel deficiency.

Silicon

Silicon may be needed for bone calcification

Tin

Tin is needed for growth in some animals. It isn't known if it is needed for human growth.

Vanadium

Vanadium is needed for growth, bone development and reproduction.

Minerals to Think About

Arsenic

Arsenic promotes growth in chickens (it's often added to chicken feed), but is not known to do so in humans. Arsenic has been beneficial in treating some forms of leukemia. It is also a notorious poison, one to which humans can tolerate, and in fact habituate to, in small doses.

Lead

Lead is a positively charged heavy metal that is similar to iron, calcium and zinc and can displace them in metabolism. Lead blocks cofactor sites for these other minerals on enzymes inhibiting their function. Lead is not removed from the body and accumulates in bone marrow and brain tissue. Lead causes nerve damage, kidney damage and red blood cell damage, among other problems. Lead poisoning causes mental impairment in children, which can be permanent. Lead poisoning can be fatal.

In the past, lead contamination from paint was prevalent because lead was an additive to the pigments used in paints. In the United States, it is now illegal to have leaded paint. Unfortunately, older homes can still have leaded paint on their walls, and children sometimes eat anything. Lead is also used in making fine crystal, and amounts can be leached out when acids are placed in the crystal. Ceramics purchased in other countries may have been made with leaded paint.

Older homes may also have plumbing that used lead solder. Lead is leached from the pipes into water, more so hot water than cold. Sufficient lead leaches into standing pipe water so that one should let water run for up to a minute prior to using it, or use filtration systems when pipes contain lead solder. (Household water can be tested for lead levels.)

Leaded gasoline was also a common cause of lead poisoning through the 1970's. The lead was in emissions and entered the food chain through contaminated soils and from coating plant surfaces. Grazing animals often exhibited symptoms of lead poisoning. Leaded gasoline is no longer legal in the United States.

Mercury

Methyl mercury is toxic. Mercury blocks many, many cofactor sites and in general, inhibits metabolic reactions. Methyl mercury is naturally found in sea water, and is a contaminant of a number of industrial processes, including the printing industry, and formerly, the felting process used in hat making (the origin of Lewis Carroll's Mad Hatter). Although major efforts have been done to minimize industrial mercury contamination of water supplies, fish are a still a primary source of mercury. Some areas, notably active volcanic areas, also emit mercury that contaminates soil, and is inhaled. In the past mercury fungicides were common, and consumption of grain coated with mercury fungicides caused serious mercury poisoning. Mercury can be leached from the body by sweating, and some chelating agents bind to mercury in tissues and can then be excreted. Mercury poisoning can be fatal.

Children and pregnant women should restrict their consumption of fish to avoid accidental mercury contamination. Larger ocean carnivorous fish (such as swordfish and tuna) contain the most mercury because of biological magnification in the food chain. Fish taken from mercury contaminated waters also contain unhealthy amounts of mercury.