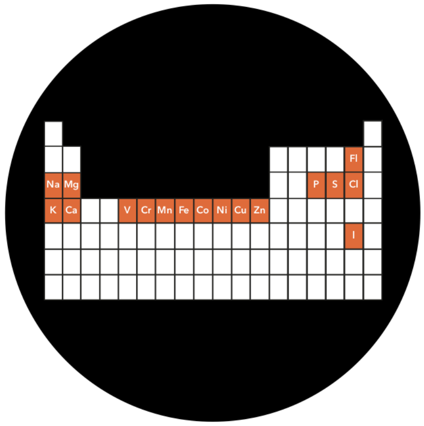
Chapter 6. Minerals



6.1 Mineral Needs

Mineral elements originate in the Earth and are extracted from soil by plants. There are 15 known carbon-containing organic and inorganic minerals that are physiologically essential in the human diet. The mineral sub-classifications are **major minerals**, which are needed in daily quantities of more than 100 milligrams, and **trace minerals**, which are needed in quantities less than 100 milligrams per day. The third class of non-essential **ultra-trace minerals** in foods and water also have biological activity in humans, but restricted dietary intake of this mineral class is not accompanied by deficiency symptoms.

A number of research methods and experimental designs have been used to determine the Recommended Dietary Allowance (RDA) for approximately two-thirds of the essential dietary minerals. Balance studies are used to estimate the amount of a given mineral that is required in the diet to maintain a homeostatic balance in the body. This level is achieved when dietary intake is adequate to offset bodily losses. **Turnover studies** employ a comparable design to balance studies in that controlled amounts of minerals are administered and losses are measured. In turnover studies, however, the minerals are radioactively labeled so that absorption and bodily retention of minerals can be more thoroughly evaluated. This has been helpful to learn about the mineral requirements of specific tissues, such as the thyroid gland iodine uptake and retention, which is the indicator for the iodine RDA. **Factorial analysis** is a more complicated technique to estimate daily mineral requirements, whereby constants for mineral absorption and losses across varying dietary intake levels are developed and used in regression models. These factors, or established relationships between intake, absorption and mineral losses, allow for a reliable calculation of daily need.

Since there is insufficient scientific evidence to establish an Estimated Average Requirement (EAR) for the other one-third of essential dietary minerals, healthy population intake data was used to establish an

Adequate Intake (AI) level. The AI for minerals were developed using survey instruments to estimate the average daily mineral intake of healthy adults.

For most minerals, daily requirements are the same for adult men and women of various ethnicities. For some minerals, though, there are differences between the sexes in the absorption efficiency or retention of dietary intake. Manganese, for example, is less effectively absorbed by men, who have lower concentrations of serum ferritin than women. Since manganese is thought to be absorbed in proportion to serum ferritin levels, the daily allowance for men is slightly higher. Iron is another example; menstruation cycle blood losses must be offset by considerably higher daily requirements for women. For calcium and the electrolyte minerals, race/ethnicity has been a subject of consideration in determining optimal levels of daily intake, but available evidence does not warrant different mineral intake requirements for individuals along these lines.

MAJOR MINERALS > 100 mg	RDA/AI*	
	MEN	WOMEN
Magnesium mg	400	350
Phosphorus mg	700	700
Calcium mg	1000	1000
*Sodium*mg	1500	1500
Chloride	2300	2300
*Potassium	4700	4700

Recommended Daily intake and Adequate Daily Intake of **Major** Dietary Minerals

Another factor that may greatly affect someone's daily requirement for minerals, particularly electrolytes, is their reliance on thermoregulatory responses. Warmer environments and increasing internal muscle temperatures from physical activities or exercise stimulate increased water losses from the skin in an effort to cool nearby passing blood by convection. Elevated sweat rate increases mineral losses; however, within a relatively short acclimation period lasting only several days, sweat mineral losses normalize, and homeostasis is maintained even at comparably high temperatures and activity levels. Even still, research used to establish the AI consistently emphasizes that the levels deemed adequate for healthy adult men and women do not apply to individuals who lose large volumes of sodium and potassium in sweat, such as competitive athletes and workers exposed to extreme heat stress (e.g., foundry workers and firefighters). While it is also generally accepted that certain types of exercise may increase an individual's need for bone minerals, namely calcium and phosphorus, there is currently insufficient evidence to justify different intake recommendations for people with different levels of physical activity. A larger consideration in determining the daily intake requirement for minerals is their bioavailability. Some minerals in the diet are highly bioavailable; they are absorbed and retained in a high proportion of intake. Most minerals, though, are affected by one or more digestive or dietary factors that inhibit their effective absorption. On the contrary, some dietary factors, such as ascorbic acid, enhances mineral absorption. Mineral bioavailability is also

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Recommended Daily intake and Adequate Daily Intake of Dietary **Trace** Minerals characterized by bodily retention, which for certain minerals is impaired with higher intakes of caffeine, alcohol or even other dietary minerals. The various factors that impair and enhance mineral bioavailability will be discussed in detail in section three of this chapter.

Epidemiologically scaled food intake studies indicate that the average US diet meets the daily requirements for two-thirds of the essential dietary minerals. Problematic nutrients that are persistently imbalanced in the diets of average US adults include **sodium chloride, potassium, calcium, magnesium**, and for women, **iron**. The amount of all of those minerals except magnesium must be listed on the Nutrition Facts Panel with a level of reliability within 20% of the actual value. The Daily Values for these minerals are based on a 2000-calorie diet with a focus on the RDA for women for iron; for calcium, on the RDA for adolescence and 70+ age groups; and for sodium, on including the molecular weight of chloride.

6.1 Homework 1

Homework • Answered

Which of the following minerals is needed in the daily diet in **trace** amounts?

- ○ **A** magnesium
- ○ **B** phosphorus
- ◉ **C** iron
- ○ **D** sodium

Explanation

Iron is a trace mineral - the daily intake requirement for the trace minerals is less than 100 mg per day. The daily requirement for the other minerals listed are higher than 100 mg per day.

Answered - Correct!

No attempts left

6.1 Homework 2

Homework • Answered

Which of the following minerals has a different daily allowance for men and women?

- A Magnesium
- B Zinc
- C Manganese
- D Iron
- E All of the above

Explanation

All of the listed minerals are recommended for men and women in differing amounts

Answered - Correct!

1 attempt left Retry

6.1 Homework 3
Homework • Answered

Touch the set of minerals that are required on the Nutrition Facts Panel

✓ Correct!

Targets placed: 1/1

Undo Delete selected Remove All

You can place up to 1 targets

Answered - Correct!

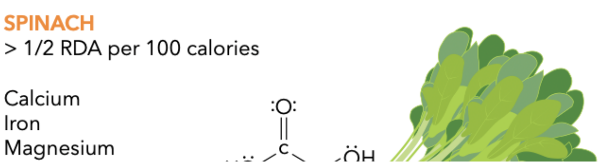
1 attempt left Retry

6.2. MINERAL SOURCES

Minerals in the diet are provided directly from plants, water, animal tissue and milk, as well as from fortified foods and supplements. The mineral content in foods can be measured using colorimetric and ashing techniques. **Mineral ashing** relies on heat combustion or acid digestion to destroy the organic matter. The remaining inorganic ash, which is typically less than 5% for most whole foods, is used to evaluate grain and bran quality and subjected to subsequent analyses to measure the level of individual minerals present.

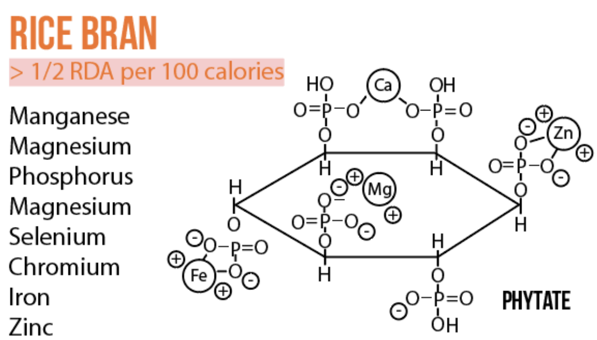
Data collections for total ash and separate mineral content are published in the USDA Nutrient Database for eight (sodium, chloride, potassium, calcium, phosphorus, magnesium, iron and zinc) of the 15 dietary minerals. A handful of the trace minerals (selenium, copper manganese, moly, chromium, and fluoride) may be found in the expanded database collection, but only for a small number of foods in which approved methods of analysis were used. These minerals are not listed by default because they are either adequate in the average adult diet or relatively ubiquitous in foods or because the quality and amount of data in the collection is too small or variable to publish.

Large pools of data are needed to provide enough statistical power to identify the less obvious variables that affect the mineral content of foods: variables such as geochemical soil relationships, cooking and processing treatments, or even intra-species genetic nuances. Copper in foods is a good example; it is not as affected by predictable geographic soil differences like most other minerals, but in acidic foods that are heated in stainless steel containers, copper accumulates. Or Brazil nuts, for instance, which contain up to 20 times more selenium than other nut species, and more than10 times the RDA per one ounce serving. As nutrition science advances and more is learned about minerals in foods and, more specifically, the factors that significantly influence their levels, the food composition databases will expand to include the other dietary minerals that have an established RDA or AI.



For dark green vegetables that are high in water weight, the comparison of mineral content is better expressed per calorie than as a function of serving size. For example, 100 calories of **spinach** provide over half the daily allowance for seven out of the nine minerals that are included in the USDA nutrient database collection. This level of mineral density rivals synthetic multi-mineral supplements. However, since spinach is a high-**oxalate** food, contributing more than 3400 mg in that same 100-calorie serving, mineral absorption may be compromised. While not as oxalate-rich as spinach, other mineral rich foods like sweet potatoes and cabbage also have a compromised mineral bioavailability. **Kale family** greens, like bok choy, are excellent green leaf choices as they are only slightly less mineral-rich than spinach leaves, but very low in mineral-binding oxalate.

Grain and legume **seeds** are also highly concentrated in many of the essential dietary minerals, particularly phosphorus, magnesium, chromium, iron, zinc silicon, and manganese. Just 100 calories of rice bran, for example, satisfies more than half the daily requirement for all these nutrients. The mineral density of grain and legume servings is reduced with cooking and in a fashion proportional to increasing water content. Other processing treatments, like refining and milling, also reduce the natural mineral concentration of foods because the majority of minerals are concentrated in the bran and germ portion of seeds. The bioavailability of seed minerals is also highly dependent on another constituent in the aleurone layer and germ of seed grains, which is called **phytate**. Phytate is an organic compound that, like oxalate, binds to minerals in the intestines and renders some minerals too complex to absorb. Thus, although refined grains and flours with the bran



and germ removed contain significantly less total minerals per serving, the lower phytate content reduces mineral absorption interferences. Since chemical bread leaveners and some yeast bacteria have the enzyme to hydrolyze phytate, leavened and fermented bread products have less phytic acid than unleavened bread and breakfast cereals.

Animal foods also provide minerals in the diet. Organ meats, especially liver and spleen, are the most concentrated mammalian source of iron, zinc, selenium and copper, as these organs are the primary storage site in live mammalian tissues. Fresh mollusk oysters and other oyster varieties from the Atlantic are the most concentrated non-mammalian sources in iron, zinc, selenium and copper, and also contribute significant amounts of dietary iodine. While these animal sources are highly concentrated and highly bioavailable, they are rarely consumed in the US and consequentially do not contribute significantly to our total daily intakes. Red meat, a less mineral-dense but more commonly consumed meat than organ meats, contributes far to our total daily intakes of iron and zinc. **Milk** is another significant source of dietary calcium, phosphorus and zinc on account of its popularity and fluidity which can be concentrated in milk products like milk cheeses and yogurt.

Figure 6.5. Minerals From Water

With the exception of fluoride **drinking water,** water is not generally considered a significant source of most minerals in the North American diet. Depending on one's location and consumption levels, however, water can contribute significant amounts of sodium, calcium, selenium, copper, and especially fluoride – a mineral added to water at a concentration of approximately 6.7 mg/liter on average. Popular foods and beverages that are prepared with tap water like beer, coffee, soft drinks, juices and teas contain appreciable amounts of chromium and boron. Other trace minerals, including boron, arsenic and chromium, can also found in tap water at low levels. Additional minerals like chromium are often added to tap water sources via yeasts used to ferment alcoholic beverages, or via tea leaves, which accumulate fluoride and manganese that is infused into drinks by steeping. The mineral concentration of decaffeinated tea is approximately twice that of caffeinated varieties. Although teas are rich sources of minerals, the tannins present in tea moderately reduce their bioavailability.

Added minerals can improve the nutritional value and functionality of prepared foods. Certain minerals like sodium and chloride are only consumed in additive form. Supplemental nutrition products include single and multi-mineral combinations that can enhance mineral bioavailability like calcium, for instance, which is often complexed with vitamin D, or iron, as another example, complexed with vitamin C.

The most abundant added mineral in the diet is sodium. Only a small amount of commonly eaten foods contains natural free and non-chlorinated sodium. The levels of sodium provided in water and natural food sources like celery, milk, and shellfish contribute less than ten percent of our total sodium intake in the typical diet. The other ninety percent of our sodium intake in the US comes in the form of **sodium chloride**, better known as salt. Chemically, salt is a 1:1 molecule of sodium and chloride that weights 58.8 mmol. Processed and **restaurant foods** tend to have high amounts of sodium chloride due, in part, to their prized preservative and sensory effects on food flavors. One of the densest salt foods is orange chicken, a favorite among children and adults alike, which provides 3500 mg of sodium per 675-gram portion. Other sources of excessive sodium intake include quick service foods like biscuits, breakfast sandwiches, fried chicken and, most popularly, burgers and pizza, the two most prevalent sources of salt from fast foods in the typical US diet.

Salt is also used to enhance the flavor of foods cooked **at home**, and sometimes again at the table with service, based on personal salt preferences. This category of salt intake contributes only about 10% of the total in our diets. The other 90% is from packaged food products, which, like restaurant foods, are problems due to their popularity and portion-sizing. **Convenience foods** and pre-seasoned meals, including soup mixes, are among the largest sources of salt intake in our diets. Sunflower seeds, for example contain 1700 mg of salt in just one ounce. Canned foods, soups and processed cheese products are also high in sodium relative to their serving sizes providing as much as 2500 mg of sodium per standard serving.

While these processed foods undoubtedly use salt to enhance food flavors, salt in processed foods is used for many other functional, value-adding reasons. For instance, sodium chloride is essential for making yeast doughs rise, and keeping microbial and mold growth at bay. Sodium bicarbonate aluminum phosphate salts are also used to make bread, but as leavening agents in non-yeasts doughs, which also benefit from sodium as a conditioner to strengthen their proteins (or gluten) and allows doughs to hold air and not collapse. Sodium is also a highly-effective **food preservative** that extends the shelf-life of many types of high-moisture foods by limiting the amount of free water that is available to interact with the environment's spoiling accelerators and, more importantly, pathogenic microorganisms that need the water to replicate to unsafe levels. This preservation technique has been employed since antiquity in curing meats and pickling vegetables to extend shelf life but is less common today, excepting sausages and certain salamis. Sometimes, sodium is added to frozen foods to preserve texture. It is also used to make fermented products like soy sauce. Many low-sodium replacement products are marketed more today than ever before, but to meaningfully reduce sodium intake will require changes in individual behavior towards salt consumption, increased collaboration of the food industry with public health officials, and a broad spectrum of additional research focusing on, *inter alia*, creating low sodium food alternatives that maintain consumers' cost, flavor, and texture expectations.

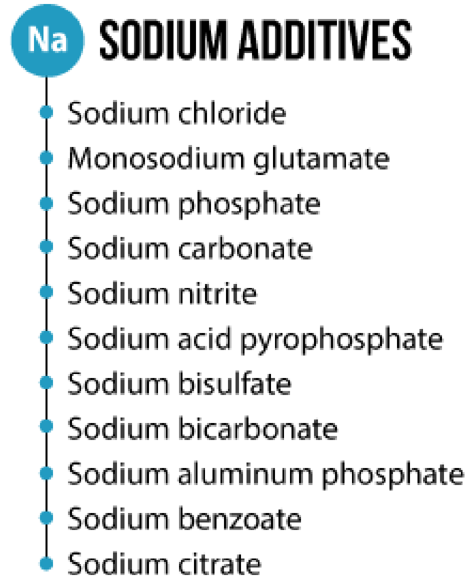


Figure 6.7. Sodium Additives that are used in Processed Foods

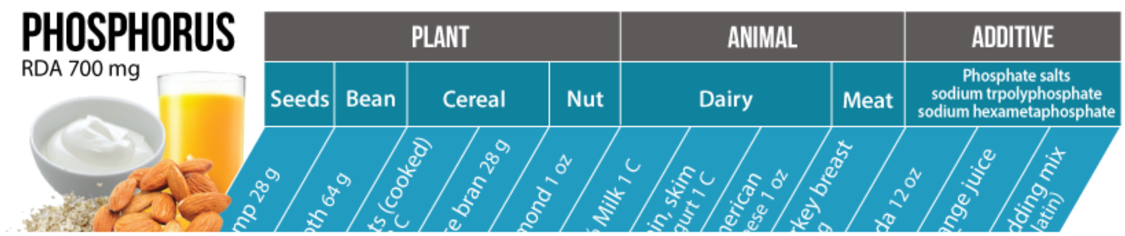


Figure 6.8. Phosphorus Rich Foods

Phosphorus is abundant in many foods in the diet and is most commonly found in nature in its pentavalent form in combination with oxygen, as phosphate (PO_4^{3-}). The most concentrated natural phosphorous is the exterior bran of **raw grain seeds**. Rice, oats, teft, amaranth and quinoa seed casings are amongst the most concentrated, but none more so than the germ portion of cooked wheat germ, which provides as much as 200 mg in just a 10-gram TBSP serving. **Cow's milk** and dairy products, while slightly less phosphorus-dense than seed bran, are a more significant source of total phosphorus intake in the daily diet. Yogurt is significantly higher in phosphorus than milk due to its lower water content. Processed cheese is higher than traditional cheese by as much as 50% as a function of bacterial degradation by cheese-producing bacteria. Servings from foods in these groups provide around 250 mg of phosphorus per serving, on average.

Meat, fish, and poultry contribute comparable phosphorus concentrations to those provided by plant seeds and dairy. While meat and dairy have a less favorable phosphorus to energy ratios than do plant foods, the phosphorus is more bioavailable. While phosphorus (as phosphate) content has always been largely uniform across most plant and animal tissues, even among varying species and regions, average phosphate levels in the diet have risen 10-15% in the last quarter century.

This difference is due to increased calorie intake and use of phosphorus-based food additives. Cola soft drinks that use phosphoric acid as the acidulant contribute 50 mg (< 2 mmol) of phosphorus per 12 oz. can. While the quantity provided by one serving is relatively minimal (only 5 % of the typical daily intake), in adults who drink multiple servings, acidulated sodas can be a significant source of daily phosphorus intake. Phosphorous also appears in a majority of **multivitamin/mineral** supplements in varying concentrations that average around 100 mg, most often complexed with calcium. Adults, on average, consume more than two times the RDA for phosphorus. However, phosphorus salts that are used in food processing applications (similar to those described above for sodium) are not always included in food nutrient composition databases, leading to postulations that phosphorus intake in the US is significantly underreported.

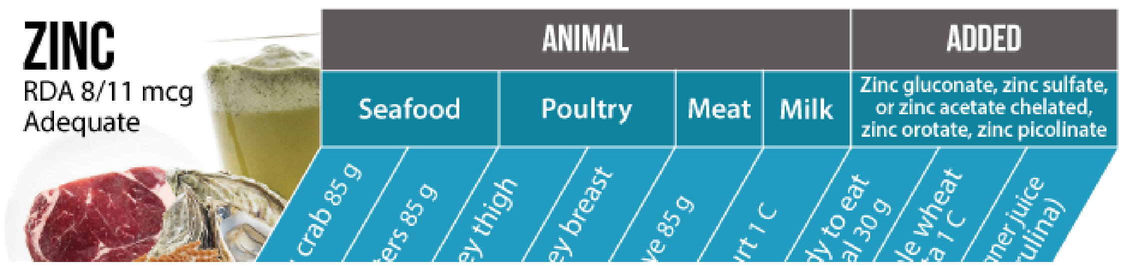


Figure 6.9. Zinc Rich Foods

Zinc is provided in the highest concentrations in sea **animals**. Fresh Eastern oysters that have been canned are the most concentrated source of zinc in human diets. Oysters and other mollusks are an estimated 10% zinc by weight and provide over eight times the daily zinc allowance in just one 3 ounces serving. Mollusks that are farm raised or cooked are slightly lower in zinc but still provide more than five times the amount needed in the daily diet. Red meat is the most common zinc source in the US diet with each serving providing 10-mcg. Poultry is also an important source of zinc in the diet but is, overall, significantly lower in zinc than beef, with the highest concentrations provided by dark meats of wild bird varieties. **Plant zinc** is less abundant in the diet. One rich plant food is 85% cocoa dark chocolate, containing nearly one half our daily zinc requirements in just one ounce. Other bean varieties, like the Hyacinth, moth, and soybean, provide around 4-6 mcg zinc per 64 g (1/3-2/3 C), with canned and baked versions highest in the range. Certain nuts and seeds offer just 1 and 2 mg of zinc per ounce. As a result, low-protein and vegetarian diets tend to be low in zinc, prompting a few brands to mock meat alternatives and diet shake meal-replacers to supplement their products with half of our zinc daily allowances.

The most concentrated source of added zinc is fortified, ready-to-eat breakfast cereal, with a small standard 30-gram serving providing over 1 1/2 times the daily allowance. Zinc is also commonly included in multivitamin and mineral supplements as organic complexes, or chelated zinc.

Dietary Calcium comes from natural and fortified food and water sources as well as dietary supplements. Just around three-quarters of the 900-1,300 mg of calcium intake per day in the US, comes from **dairy products**, including foods to which dairy products have been added (e.g., pizza, lasagna, dairy desserts). Together, dairy foods contribute, on average, one-third of the daily allowance per serving, of which an estimated one-third is bioavailable. There are large in-category differences, especially for cheeses with varying moisture content. Parmesan cheese, for example, has 1 1/2 times more calcium per one ounce serving than does a higher-moisture cheese, like provolone. **Dairy alternatives,** (e.g., nut and legume milks) are often fortified with calcium to a level that matches the amount available in cow's milk.

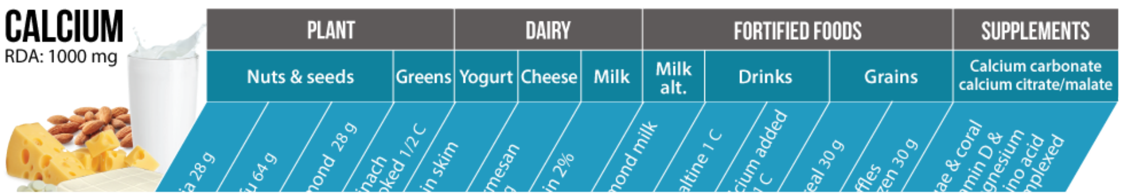


Figure 6.10. Calcium Rich Foods

While a small amount of calcium is consumed in meat, eggs and fish where the bones are eaten, such as with sardines or ground meats. More dietary calcium is provided from natural and fortified plant sources. **Green vegetables**, especially in the leafy families like that of spinach and kale (i.e., broccoli, bok choy, cabbage, mustard, collard and turnip greens) are rich in calcium per calorie, especially when cooked. Fruit is low in natural calcium, but **fortified fruit juices**, such as orange juice, contribute significantly to calcium intake providing, on average, 100% of the daily need for calcium in one 8-oz. glass. Grains, while not particularly high in calcium per serving, do contribute a significant amount (5%) of calcium in the daily diet because of their consumption levels; especially for cultures where flours are processed with calcium-containing **leavening agents** (i.e., baking powder) and **preservatives** (i.e., calcium-propionate), and where grains are fortified as part of federal health initiatives. Baked grain products providing significant dietary calcium are **corn tortillas** and **sandwich bread**, which ranges anywhere from 25-50 mg of calcium per standard serving. A larger amount of added calcium is obtained from enriched ready-to-eat breakfast cereals which are, in some operations, sprayed with calcium carbonate at a level to satisfy 100% RDA per 30-gram serving. Calcium-added food products are popular in the breakfast categories of frozen waffles, smoothie kits and a wide variety of drinks, bars and shakes designed as breakfast replacements. Microwave meals sometimes feature added calcium, with the highest fortified brands meeting 75% or more of the RDA. Legumes, nuts and seeds also contain a significant amount of calcium by weight. Soy beans and soy products, like calcium-set tofu, are also high in calcium – the latter satisfying half the RDA in one 3-ounce serving notwithstanding the limited bioavailability.

Dietary calcium supplements are consumed by about 40% of adults in the US for life-stage related or therapeutic reasons. Supplement labels are required to list the calcium content of the supplement as elemental calcium, which expresses the amount of calcium that is biologically active. Labels also include calcium source, which can be natural, from seafood or harvested bacterium sources (i.e., spirulina) or synthetic. A majority of calcium supplements feature added vitamin D, and many brands also contain magnesium. Higher-end supplements often use amino-chelated calcium, which can be marketed for superior absorbability. Calcium supplement preparations include calcium carbonate, calcium citrate, calcium citrate malate, and less commonly, supplemental calcium lactate, calcium gluconate, calcium glucoheptonate and calcium hydroxyapatite. Calcium gluconate and calcium lactate are very expensive and used more often in clinical medical nutrition applications such as parenteral or enteral feeding solutions. In the dietary supplement category, preparations usually feature **calcium carbonate**, the most economical and concentrated calcium form, or **calcium citrate,** the more expensive and most bioavailable form available today. To obtain peak biological activity from a calcium supplement, doses of no more than 500 mg of elemental calcium should be consumed with, or shortly after, meals that are low in calcium binders.

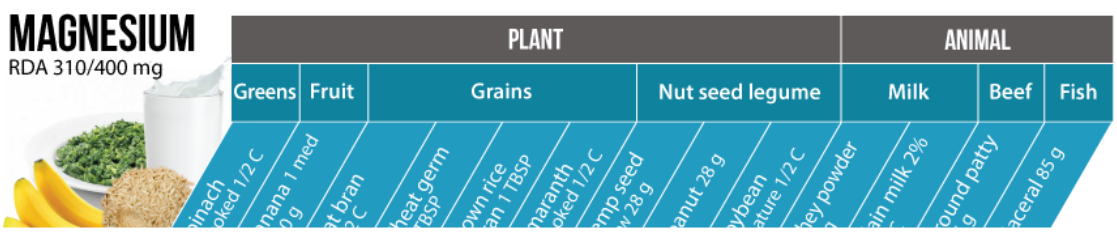


Figure 6.11. Magnesium Rich Foods

Magnesium is common in foods but varies substantially in content by food type. **Plants** are typically higher in magnesium per expression of energy calories. Green leafy vegetables like cooked spinach and Swiss chard provide 80-150 mg/serving. Dried fruits and fruit juice concentrates with banana and avocado are second to leafy greens in magnesium density, with as much as 30 mg per serving. Unpolished and unrefined nuts and grain and legume seeds are high in magnesium and contribute more than half our total daily magnesium intake in the US. Products made with flours ground from whole seeds are higher in magnesium than those made with flours that are refined, because grain seed bran and germ layers are concentrated in magnesium. Brown rice and cooked amaranth contain the most magnesium per standard (and edible) serving, with soy coming in a close third. Cooking with boiling and draining methods reduces the magnesium content of grain seeds more than methods using steaming.

Animal meat and eggs are less magnesium-dense than most unrefined plant seeds and leaves per measure of weight and energy, but still, contribute nearly one-third of our total daily magnesium intake. Caviar, oysters and dried fish are the richest animal sources, each satisfying at least 50% DV per serving; however, beef, chicken, and turkey, which each provides slightly less magnesium per equivalent serving, are the largest non-plant contributors to total daily magnesium intake. Milk also provides about 35 mg magnesium per cup.

Hard-water is a variable source of magnesium intake depending on the area from which water comes and the manner in which it is stored. Typically, water with increased "hardness" has a higher concentration of magnesium salts at a relatively insignificant concentration of 2.5 mg per cup. Magnesium supplements are available as magnesium oxide, magnesium gluconate, magnesium chloride and magnesium citrate salts, as well as a number of amino acid chelates including magnesium aspartate. Magnesium hydroxide is used as an ingredient in several antacids as well as in calcium supplements and fortified products.

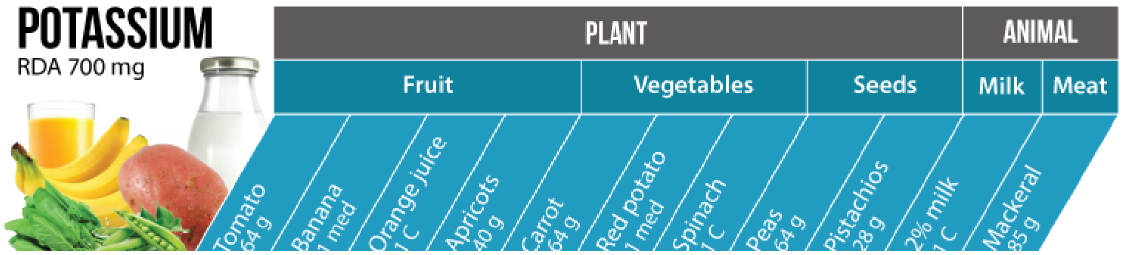


Figure 6.12. Potassium Rich Foods

Potassium in the diet is provided by plant and animal food sources. **Plant potassium** is affiliated with bicarbonate and, to a lesser extent, phosphate. The most concentrated potassium sources per calorie are leafy green vegetables such as spinach, which provides half the daily need in just one 100-calorie serving. Because leafy greens are far less calorie-rich than certain roots (e.g., carrots) and tubers (e.g., potatoes), which, because of their caloric density, meet our daily needs in just one standard serving (around 64 grams), vegetables like spinach must be consumed in amounts larger than the standard portion size (1 Cup) to total 100 calories and thus to contribute significantly to daily potassium intake. Nuts and seeds are generally low in potassium, but some nut species like pistachios can provide a significant contribution to our daily allowance.

Potassium is less abundant in **meat** but is provided in concentrated amounts in salmon, mackerel and some cuts of poultry. Milk is a major source of potassium in the diet, providing almost half of our daily allowance in just one of two-to-three recommended servings. Less obvious sources of dietary potassium include leavening agents, like baking powder, molasses, tea and spices. By weight, these sources are highly concentrated in potassium or around 16%, but collectively, these foods do not contribute significantly to our overall dietary intake.

Potassium is also consumed as potassium chloride as a **food additive** ingredient, a salt substitute, or as pills used therapeutically to treat diuretic-induced hypokalemia. Salt substitutes that are currently available in the marketplace range from 440 mg to 2,800 mg potassium/tsp, all as potassium chloride. Multivitamin-mineral supplements in the US contain a number of different potassium salts, including potassium chloride, citrate, gluconate, bicarbonate, and aspartate at concentrations not exceeding 99 mg of potassium per serving.

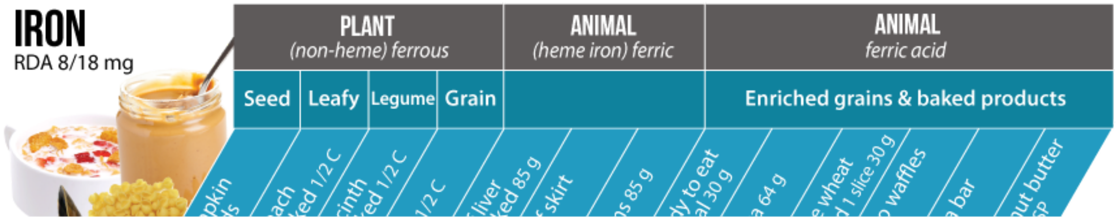


Figure 6.13. Iron Rich Foods

Dietary iron is provided in animals as heme or ferric iron. Animals store heme iron in the liver and spleen, thus, the most concentrated sources in the diet are cooked, more specifically, braised varieties of these organs. Since neither spleen nor the second most concentrated iron source, dried beluga whale (which both provide around 30 mg per 3 ounces) are common in the typical US diet, cooked liver is commonly referred to as the richest dietary source. Mollusk varieties, like clams, are also concentrated in iron, with breaded varieties containing the most iron per serving. Red and dark meat are the tops sources of heme-iron in the US, which represents just 10% of our daily iron intake, on average; even less for women.

The majority of non-heme, or ferrous iron in the diet comes from plants like grains, the richest and most prevent source of iron in the diet. While the richest plant sources of heme are **ancient grains**, especially teft and amaranth, **enriched flours** that are used to make pastas, breads and bagels contribute significantly to our dietary intake of iron in the US. **Breakfast cereals**, fortified with iron to meet 100% of the RDA for women, provide as much as 18 mg per 30 g serving. Many other breakfast foods in juice, pastry and meal bar formats also provide added ferric acid. In the legume family, soy beans are the highest in iron, providing as much as 10 mg per ½ C when mature. Pulse beans such as navy, kidney and white beans contain just 4-5 mg per ½ C, which is still, on average, 25% more than the highest iron-containing cooked vegetables, like potatoes and spinach. While nuts are not a significant source of iron by themselves, when paired with 85% dark chocolate cocoa, which provides 3.5 mg per ounce, they are an excellent source of iron.

6.2 Homework 1

Homework • Answered

Which of the following legumes has the MOST phytic acid?

- (•) **A** Raw beans
- ( ) **B** Soaked beans
- ( ) **C** Fermented beans

Answered - Correct!

1 attempt left Retry

6.2 Homework 2

Homework • Answered

_______________ is the most commonly used mineral additive in the United States.

- (•) **A** sodium chloride
- ( ) **B** potassium chloride
- ( ) **C** magnesium salts
- ( ) **D** iodized salts

Answered - Correct!

No attempts left

6.2 Homework 3

Homework • Answered

Match the following minerals with their most concentrated or most abundantly consumed food source

Premise		Response
1 Phosphorus	→	A Seeds
2 Magnesium	→	B Leafy greens
3 Zinc	→	D Oysters
4 Calcium	→	C Milk
5 Potassium	→	E Red Potatoes
6 Iron	→	F Cooked Liver

Answered - Correct!

1 attempt left Retry

6.2 Homework 4
Homework • Answered

Fortified and ready to eat breakfast cereals are formulated to meet the RDA for what two minerals?

✓ Correct!

Targets placed: 2/2

Undo Delete selected Remove All

You can place up to 2 targets

Answered - Correct!

1 attempt left Retry

6.3 Mineral Processing

Digestion & Absorption

Mastication of foods by the teeth and tongue begin the process of mineral absorption. Compressive and shearing chewing forces break apart food matter to increase the surface area of ingested foods, and to expose dietary minerals for catalytic activities that take place in the stomach.

Gastric acidity facilitates the activities that prepare minerals for absorption farther down the gastrointestinal tract. A portion of the ferric (Fe3) iron from plant foods, for instance, is solubilized and **reduced** to a more absorbable ferrous iron (Fe2) by **ascorbic acid** from consumed foods or from gastric membrane enzyme **ferri-reductase**. Iodine is also reduced in the stomach to the biologically active metabolite, iodide, in preparation for absorption. The stomach is also where inorganic minerals that are complexed in foods with protein, such as phosphate and zinc are liberated, and where some trace minerals, like iodine and fluoride, are fully absorbed.

Most mineral absorption takes place along the intestinal tract. At the most proximal section of the duodenum, highly-reduced **ferrous heme-iron** is hydrolyzed from the protein globulin portion by digestive proteases. **Heme oxygenases** simultaneously degrade ferrous iron to CO_2, monoxide, bilirubin and free heme iron for transport across the membrane by transport protein, HCP 1. Slightly more distally in the duodenum, reduced **non-heme iron** is transported across another iron specific protein carrier, DMT-1, into the enterocyte where it will either be stored as **ferritin**, or moved through the basolateral membrane through the iron transporter, ferroportin.

The duodenum and upper jejunum are the primary sites for transcellular calcium and phosphorus absorption. Only a small amount of calcium and phosphorus can be absorbed paracellularly; the majority is shuttled into the enterocytes with the calcium transport protein, TRPV6. The synthesis of the TRPV6 protein carrier is stimulated by calcitriol-sensitive receptors on the enterocyte that are sensitive to passing serum calcium levels. Ultimately, this mechanism dictates the amount of calcium and phosphorus that is absorbed from the GI tract at low and moderate intake levels and, as explained in Chapter 6, is wholly dependent on the function of vitamin D3. The role of vitamin D3 in the absorption of calcium is most apparent in the upper small intestine, where **D3 receptors** are expressed in the highest concentrations, and where D3 signaling of **calbindin**, the calcium transporter, is most active.

Along the duodenum, the trace minerals zinc, chromium, manganese, and selenium, as well as a small amount of remaining copper and molybdenum are absorbed. Most trace minerals can be absorbed paracellularly in high doses but, under typical dietary conditions are absorbed transcellularly by absorption systems that may or may not be saturable, and may or may not be active. Farther down the small intestine into the ilium, magnesium absorption continues, and any remnants of biologically-available minerals that escaped are absorbed.

The large intestine is the major site of absorption for electrolyte minerals. The primary electrolyte absorption mechanism involves **carrier-mediated diffusion** down an electrochemical gradient. This mechanism is driven by the high concentration of ions in the lumen, which create a driving force for pushing or pulling electrolytes between the lumen and vascular space. The majority of potassium, sodium and chloride move across sodium and potassium **channels**. Once inside the enterocyte, sodium is actively transported into the blood by the Na+ /K+ -ATPase **pump** located in the basal and lateral membranes of the epithelial cell. Potassium ions follow sodium in equal proportion to match the hydrogen ions being pumped out, and chloride ions are carried by sodium; an absorption mechanism called **facilitated transport.**

Absorption Efficiency and Bioavailability

Minerals are absorbed with varying rates of efficiency. For instance, trace minerals like fluoride and iodine have extensive para-cellular absorption so they tend to have higher absorption efficiencies ranging between 90-100%. Minerals that are absorbed at multiple points along the intestinal tract, or in proportion to dietary intake also have high rates of absorption efficiencies. For instance, the electrolyte minerals exhibit efficiency ranges of 85-95% and 95-100% for potassium and sodium, respectively, and despite the body's tight homeostatic controls. For several key dietary minerals though, absorption efficiency ranges are much lower due gastric-mediated homeostatic controls that limit mineral absorption. For instance, calcium, magnesium and copper require saturable, carrier-mediated systems that have a limited capacity, so that dietary intake and mineral absorption are inversely related. Phosphorous and calcium absorption are reliant on adequate vitamin D status for calcitriol-mediated **calcium transport protein** synthesis and activation, as well as whole body calcium and bone tissue homeostasis. Mineral absorption efficiency is also highly predicated on the immediate physiological need for the nutrient, especially in the case of zinc absorption, which fluctuates not by zinc intake but rather by endogenous zinc production and excretion.

Dietary factors present during digestion can play a significant role in mineral absorption. Generally, minerals are better absorbed in the simultaneous presence of foods in the gastrointestinal tract. **Dietary protein** enhances intestinal mineral absorption of calcium and magnesium, and when dietary intake of protein is low, absorption of those minerals is compromised. **Animal sources** of most minerals, especially iron and zinc, are more efficiently absorbed than equivalent amounts of plant seed sources. Heme-iron from meat and seafood, for example, is absorbed 15% more efficiently than from non-heme legume sources. This difference is significant considering that maximum heme absorption is only 25%, and when alone, seeds in these legume families exhibit non-heme absorption efficiencies of just 1-2%.

Enhancers of Mineral Bioavailability

Iron absorption efficiency is much higher in the presence of **ascorbic acid**, which increases iron absorption three to six-fold. As little as 50 mg of ascorbic acid aids in eliciting heme-iron absorption by reducing dietary ferric to ferrous iron and forming a soluble iron-ascorbic acid complex in the stomach, so that iron cannot be complexed with an insoluble mineral in the small intestine. The effects of ascorbic acid on absorption are therefore greater in foods of plant origin.

Certain minerals, like selenium and phosphate, are absorbed more efficiently in organic, **protein complexed** forms, as opposed to free and inorganic forms. Selenomethionine, for example, is the natural organic selenium complexed to methionine. The absorption efficiency of organic selenomethionine is over 90%, but inorganic, free selenate and selenite, common in mineral supplements, are only absorbed at around 50%. This variability is also seen with phosphorus; from animal foods, almost 100% is absorbed, but from plant foods, averages are just under 50%.

Phytic acid in plant seeds, beans, peas, cereals and nuts is
an organic acid that interferes with the absorption of calcium, iron, magnesium, manganese and zinc.

Inositol hexaphosphate, also known as the phosphate group of phytate, binds to minerals causing them to precipitate in the lumen. This reaction renders the minerals less available for absorption. The metal binding property of phytic acid decreases proportionally as fewer than six phosphate groups are bound to each inositol molecule. Thus, when unabsorbed **calcium** in the digestant complexes with the phosphorus molecules of phytic acid, it exacerbates the precipitative effects and renders the compound indigestible. This partially explains calcium's interference with absorption of the other phytate-sensitive minerals: iron, zinc, manganese and magnesium. Calcium can impair phosphorous absorption by binding to form phosphorus complexes that are excreted in feces or by reducing the bacterial degradation of phytic acid by the bacterial enzyme, phytase. **Mineral-to-mineral interferences** are not limited to calcium. Copper and zinc compete for a divalent metal protein transporter that prefers copper. The attraction for copper actually results in reduced copper absorption and, as a result, increased proportional zinc absorption. Other **organic acids**, such as oxalic acid, tannins, or polyphenols in red wine and tea, also bind calcium and iron to form an insoluble complex that bypasses the intestinal lumen. The inhibitory effects of tannic acid increase with increasing tannin intake, and in the case of non-heme iron, are reduced by the presence of ascorbic acid. **Fiber** also interferes with mineral absorption, but in a manner that decreases transit time and increases total fecal mineral losses. Magnesium is the most sensitive to the inhibitive effects of fiber, with absorption efficiency nearing half when consumed with dietary fiber levels in the RDA.

Distribution and Homeostasis

Most absorbed minerals are transported from the intestine to general circulation bound to serum **transport proteins**, such as albumin and transferrin. Minerals that stay in the whole blood like phosphorus (40 mg/dl) for instance, circulate in free form or as part of lipoproteins and red blood cell phospholipid membranes that continuously circulate the body. A proportion of minerals are routed for target tissues throughout the body for **intracellular** storage and activity. However, the post-absorptive cellular uptake of minerals depends largely on cellular functional requirements and mineral storage capacity. For instance, red blood cells, hepatocytes and myocytes will pump in 80% of absorbed potassium, but only a fraction of absorbed sodium. The other 20% will remain in the **extracellular space** along with the largest proportion of absorbed dietary sodium and chloride to circulate the intravascular space and exchange between **interstitial spaces.** The disproportionate concentration gradient between the body spaces is maintained by an active and energy-dependent exchange of sodium and potassium across the cell membranes and the resultant electrochemical force that attracts water.

Electrolyte Mineral Distribution

Figure 6.17. Sodium Balance

Sodium homeostasis is maintained by a negative loop feedback system between the kidneys and neuroendocrine system. In response to **decreased blood sodium** and renal pressure in the renal arterioles, as well as sympathetic nervous system stimulation, the kidney produces renin. Renin, released from the juxtaglomerular cells of the kidney, cleaves circulating angiotensinogen to form angiotensin I, which is converted to angiotensin II by angiotensin-converting enzyme (i.e., ACE-enzyme)—a widely distributed enzyme in the body. Angiotensin II stimulates the adrenal gland to synthesize and release aldosterone, which binds to receptors in the cells of the neighboring collecting tubules. This action reduces the permeability of the nephron so that more salt is reabsorbed (i.e., kept) into the tubule. Entry of sodium into the collecting tubules is facilitated by symporter and antiporter proteins that are located on the top side membrane of the proximal tubule. In healthy adults, this feedback mechanism works with a nearly 100% efficiency.

In a reverse **renin-angiotensin** response to **increasing blood sodium** and renal blood pressure, aldosterone synthesis stops. This makes the collecting ducts *more* permeable, so that sodium reabsorption (i.e. retention) subsides and more sodium is lost in the urine. Potassium, while much less concentrated than sodium in the ECF is also filtered and reabsorbed in the kidneys, except by a **solvent drag** mechanism, that like in the gut, is highly dependent on salt reabsorption.

Serum calcium concentration is, on average, 10mg/dl; half that is free and ionized Ca++, and the rest is complexed or protein bound. Blood **calcium homeostasis** is precisely maintained by the coordinated efforts of the endocrine, renal and skeletal systems. A slight drop in blood calcium levels (e.g., in the case of inadequate dietary calcium intake) is sensed by the parathyroid gland resulting in the increased secretion of **parathyroid hormone** (PTH). Elevations in PTH rapidly decrease urinary excretion of calcium and increase urinary excretion of phosphorus by improving its reabsorption in the kidneys. Conservation of calcium in the kidney and increased bone re-absorption of calcium and phosphate restore serum calcium concentrations.

Serum Calcium (and Phosphorus) Homeostasis

Although the action is not immediate, PTH also stimulates conversion of vitamin D to its active form, **calcitriol**, in the kidneys which, when released into circulation, increases intestinal absorption of both calcium and phosphorus, stimulates the release of calcium (and phosphorus) from bone, and limits urinary excretion of calcium. In response to increases in serum phosphorus, bone cells release a third hormone, fibroblast growth factor-23, which inhibits the production and stimulates the degradation of **1,25-dihydroxyvitamin D**, so that urinary phosphorus excretion is increased. This negative feedback loop, along with parathyroid hormone (PTH) and vitamin D, controls phosphorus homeostasis.

Dietary factors such as caffeine, alcohol and dietary protein have a modest negative impact on calcium retention and may be associated with increased **bone calcium loss**. The effects of usual caffeine intake on renal calcium excretion are short-lived and limited to no more a few milligrams of calcium per day. It has long been thought that protein caused increased **urinary calcium excretion**, but overall calcium balance appears to be unchanged by high dietary protein intake in healthy individuals with adequate supplies of protein, calcium, and vitamin D. Excess salt intake and resulting aldosterone-mediated sodium losses create re-absorption competitions in the distal renal tubule that results in increased **urinary calcium losses**. It is estimated that every 1-gram (g) increment in sodium (2.5 g of sodium chloride; NaCl salt) excreted by the kidneys can draw as much as about 26 milligrams (mg) of calcium into the urine. This effect seems to be exacerbated in white females, who experience greater urinary calcium excretion with high salt intake than females that are not white. The effects of sodium on calcium loss are lessened when dietary calcium intake is low, through the compensatory calcium conservation action of PTH.

I**ntracellular** storage and activities

Excitable nerve and muscle cells pump calcium from **extracellular space** by a voltage-dependent **calcium channel** that opens to allow calcium ions into the muscle cell. When a nerve impulse stimulates a muscle fiber to contract, within the cell, calcium ions bind to activator protein, **troponin-c,** which helps release a flood of calcium ions from calcium storage depots, the endoplasmic reticulum (ER). The binding initiates a series of steps that lead to muscle contraction. Upon completion of the action, calcium is pumped back outside of the cell or into the ER until the next activation.

The vascularized organic bone matrix cells draw calcium and phosphorus from the blood supply to use for **bone remodeling**. Bone remodeling occurs through the pairing and balanced action of bone-degrading **osteoclasts**, and bone depositing **osteoblasts**. Remodeling occurs in response to stimulation by surface-dependent factors initiated by mechanical loading and genetics. **Osteocytes** in cortical bone sense change in gravitational forces and initiate growth factors that initiate remodeling. Loading of the skeleton by mechanical means (e.g., weight-bearing exercise such as running, walking, or jumping) promotes bone formation at every stage of life, but in adults, does not change the size and shape of the bone. The unloading of the skeleton in cases of bed rest or weightlessness (i.e., space travel) is associated with a profound uncoupling of remodeling, such that **bone resorption** (i.e., breakdown) is dramatically increased, as is net bone loss.

Bone Mineral Storage

New bone is formed by intra-membranous and endochondral bone cells in microscopic elements of bone referred to as remodeling units or basic multicellular units. The osteoclastic activity results in the synthesis of **bone matrix proteins** and a **collagen platform** that is subsequently mineralized to form highly structured and organized lamellar bone. The mineralization process is driven by phosphate to form negatively charged hydroxyapatite, which subsequently avidly binds to calcium. The ion deposition and crystal formation between the collagen fibrils occur because of binding of calcium to non-collagenous proteins in the matrix. The distribution, size, and density of the apatite crystals ultimately dictate the mechanical properties and strength of the bone.

Over half of the body's fluoride is stored in the bones and teeth where it is integrated into hydroxyl in a chemical reaction in the mouth. Fluoride can be deposited in plaque or remain in the saliva and gingival fluid. In response to **demineralization** from acids in the mouth, fluoride re-mineralizes the partially dissolved crystals to form **fluorapatite**, a less acid soluble, stronger version of hydroxyapatite.

The liver also takes some minerals from portal routes and from general circulation to store for later use. Selenium, for instance, is converted to selenomethionine by glutathione peroxidase, to be catabolized for use elsewhere at a later time, via the transsulfuration pathway. The liver also stores a small amount of copper in concentrations second, only, to the brain. Endocrine glands, such as the pancreas and thyroid, receive some absorbed minerals (e.g., zinc and iodine) for enzyme and hormone production.

Terms for Iron Distribution and Storage

Transferrin delivers approximately 80% of absorbed **ferric iron** to bone marrow, where iron is granted entry complexing with a highly specific transferrin receptor located on the plasma membrane surfaces of the marrows cells. Internalization of transferrin occurs through clathrin-coated pits and subsequent endosomal vesicle acidification, which results in the release of iron from transferrin. In the marrow, a small amount of iron is stored as **hemosiderin**, but the majority of ferric iron is used for erythroblast production. In this process iron is used to make **protoporphyrin-IX**, the ligand binding component of hemoglobin, and in the muscle, myoglobin. In the liver, iron is used to synthesize transferrin and other iron-iron transport proteins, and like the bone marrow and spleen, a small amount of stored iron is kept as hemosiderin. Iron homeostasis is regulated by extracellular hepcidin, which signals for the recycling of red blood cells back to ferric iron in the spleen. The spleen sends most iron back out with transferrin but keeps some stored as hemosiderin.

6.3 Homework 1

Homework • Answered

Match each mineral to the transport protein or receptor that facilitates its intestinal absorption

Premise		Response
1 iron	→	A DMT-1
2 calcium	→	C TRPV 5/6
3 Zinc	→	B ZIP

Answered - Correct!

No attempts left

6.3 Homework 2

Homework • Answered

Match each mineral to the most accurate description

Premise		Response
1 Sodium	→	C *cation* mineral concentrated in the extracellular water compartment.
2 Chloride	→	B *anion* mineral concentrated in the extracellular water compartment.
3 Potassium	→	A *cation* mineral concentrated in the intracellular water compartment.

Answered - Correct!

1 attempt left Retry

6.3 Homework 3

Homework • Answered

Which of the following dietary compounds enhances mineral absorption?

- A Phytic Acid
- B Oxylic acid
- C Ascorbic acid
- D Polyphenols
- E Fiber

Explanation

Ascorbic acid enhances the absorption of iron, chromium, and possibly other minerals. The other compounds listed all inhibit mineral absorption.

Answered - Correct!

1 attempt left Retry

6.3 Homework 4

Homework • Answered

When the concentration of salt in the body is too high, the homeostatic response is to _____________ rennin and aldosterone release from the kidney and _____________ urinary sodium loss.

- ○ **A** increase, decrease
- ◉ **B** decrease, increase
- ○ **C** decrease, decrease
- ○ **D** increase, increase

Explanation

When serum osmolality is high, the hypothalamus and cell osmoreceptors signal to the kidneys to reduce rennin output. This in turn reduces the amount of reabsorption in the nephron which yields an increase in urinary output and sodium loss.

Answered - Correct!

1 attempt left Retry

6.3 Homework 5

Homework • Answered

When the concentration of calcium in the blood is too low, the hormonal response involves the release of ______________ from the ______________ gland.

- (●) **A** parathyroid hormone (PTH), thyroid
- ( ) **B** insulin, pancreas
- ( ) **C** growth hormone, pituitary
- ( ) **D** aldosterone, adrenal cortex

Answered - Correct!

1 attempt left Retry

6.3 Homework 6

Homework • Answered

Calcitriol causes increases in blood calcium levels by three established mechanisms that are listed below. Identify the bodily response that is not related to blood calcitriol and blood calcium homeostasis.

- (●) **A** Increased muscle cell calcium uptake
- ( ) **B** Reduced urinary calcium output
- ( ) **C** Increased bone calcium resorption
- ( ) **D** Increased gastrointestinal calcium absorption

Answered - Correct!

No attempts left

6.3 Homework 7

Homework • Answered

Match each type of tissue to the form of iron it stores or the processing of iron it performs.

Premise	Response
1 Bone marrow	C Erythropoiesis
2 Whole blood	A Hemoglobin
3 Muscle	B myoglobin
4 Spleen	D Red blood cell recycling

Answered - Correct!

No attempts left

6.3 Homework 8

Homework • Answered

Bone remodeling is best described as

- A the equal breakdown and formation of bone tissue
- B bone tissue formation that exceeds bone breakdown
- C Bone tissue breakdown that exceeds bone formation
- D the response to unloading of the skeleton (i.e., bed rest)

Explanation

Bone remodeling does not result in a net increased bone size or change in shape, and does not result in bone loss

Answered - Correct!

1 attempt left Retry

6.4 Mineral Functions

Minerals, like other nutrients, serve a wide variety of roles in the human nutrition system. The three most common functional groupings for minerals are the "**bone minerals"**, the"**hemopoetic minerals"** and the "**electrolyte minerals".** This text will use a similar, but slightly broader platform to organize the many physiologic outcomes of consuming and processing dietary minerals.

The most abundant structural minerals in the body are concentrated in the skeleton. Human bones are almost 40% minerals by weight. The hard, compact bone is rich in calcium and phosphorus as hydroxyapatite, a mineralized protein that provides bone the long-term **strength**, **elasticity** and **rigidity** needed to sustain gravity and human locomotion.

The soft tissue bone matrix is vascularized and supplies rich amounts of calcium and phosphorus, as well as magnesium and manganese, both important structural co-factors for metalloenzymes that catalyze **bone cell division** and **normal bone turnover** activities. And phosphorus, while less abundant than calcium, actually initiates the mineralization of hydroxyapatite.

Fluoride is another critical structural compound in the skeleton, mainly as fluorohydroxyapatite, a less acid-soluble, anti-ariostatic protein in teeth that **promotes remineralization** of enamel lesions and stimulates osteoclast activity.

Phosphorus is also an abundant structural mineral of the cell membrane as **phosphatidylcholine**. It is a vital structural constituent of the bi-layer with a solubility that provides membrane **selective permeability** for optimal influxes and effluxes. Phosphorus is also a critical feature of DNA and RNA.

Iodine is an essential component of the **thyroid hormones** thyroxine (T4) and triiodothyronine (T3), comprising between 60-65% of their respective weights. Thyroid hormones regulate many key biochemical reactions including protein synthesis and enzymatic activity.

Iron is a structural component of a porphyrin ring that is integrated into proteins, hemoglobin and myoglobin. Both these proteins **deliver oxygen** for diffusion throughout all body tissues. The functional capacity of the iron portion of the protein depends on its ability to form biological ligands with oxygen, nitrogen, and sulfur atoms. In hemoglobin, for instance, iron reversibly binds to oxygen within erythrocytes, and within myocytes, to heme-iron as myoglobin. In cytochromes, another heme-iron protein, iron binding carries electrons all along the respiratory chain.

Rather than directly integrating into structural tissues or cellular components, zinc facilitates proper **protein structure** configuration. Zinc's protein structure-function is a "finger-like" structure created by chelation centers that synthesize amino acids and other folded proteins. These amino acids and their anabolized proteins have roles in gene regulation for DNA transcription factors, in retinoic acid receptors for vision, and in vitamin D receptors for calcium absorption.

Functional Mineral Roles

Several dietary minerals have *homeostatic roles* in both the extra and intracellular spaces. For instance, dissolved mineral constituents in the fluid compartments of the body are critical to **water balance.** Body water balance is maintained by an equal distribution of negatively charged cations and positively charged anions between the intracellular and extracellular fluid compartments. Sodium is the principal cation of the extracellular fluid and functions as the osmotic determinant of cell and plasma volume. Chloride is the most osmotically active anion in the extracellular compartment and fluctuates with extracellular sodium levels. The major intracellular cation in the body is potassium, which has several other functional regulatory roles.

Potassium, another dissolved mineral constituent and precursor for intracellular **buffers**, is critical for maintaining intra- and extracellular **acid-base balance**. Potassium, along with phosphorus, also functions intracellularly to help prevent metabolic acidosis that occurs in response to high salt (i.e., chloride) intake. Sodium balance and blood pressure are also partially regulated by potassium in the ECF through modulating urinary sodium excretion. Magnesium is the second most abundant cation to sodium in the ECF and is necessary for fluid balance by facilitating the outward movement of potassium from myocardial cells and maintenance of EC potassium.

Free, ionized calcium, while quantitatively small, is the most common signal transduction element in biology on account of its ability to reversibly bind to proteins. **Blood clotting**, for instance, is made possible by calcium binding. As another example, intracellular calcium binds troponin to active actin and myosin ATPase to facilitate **muscle contraction** that facilitates locomotion, digestive motility and contractility of the vascular epithelial tissues. Calcium also mediates **vasoconstriction and relaxation**, or vasodilation, of blood vessels in the interstitial space.

Many of the functional roles of minerals are **catalytic**, in that minerals are critical co-factors needed to activate enzymatic action. Molybdenum, for example, is a cofactor for a number of enzymes including sulfite oxidase, xanthine oxidase and aldehyde oxidase. These **molybdonezymes** contain organic molybdopterin and are involved in the catabolism of sulfur amino acids and other heterocyclic compounds, including purines and pyridines. Zinc is another highly catalytic mineral, as nearly 100 specific **halo-enzymes** are dependent on zinc for activity. Well-studied zinc metalloenzymes include the ribonucleic acid (RNA) polymerases, alcohol dehydrogenase, carbonic anhydrase, and alkaline phosphatase.

Copper's function is also catalytic, with many copper **metalloenzymes** acting as oxidases to achieve the reduction of molecular oxygen. Lysyl oxidase, for instance, uses lysine and hydroxylysine found in collagen and elastin as substrates for post-translational processing to produce cross-linkages needed for the development of connective tissues, including those of bone, lung and circulatory system. Ferroxidase, the predominant copper protein in plasma, may also have **antioxidant** functions comparable to that of selenium and zinc, two other cellular mineral reductants. Copper is also a catalytic co-factor for the enzyme, copper/zinc/manganese superoxide dismutase (SOD)—an enzyme that provides anti-oxidant defense against damage from superoxide radicals. Dopamine β monooxygenase also uses copper, along with ascorbate, and O_2 to convert dopamine to norepinephrine, a **neurotransmitter** produced in neuronal and adrenal gland cells.

Other dietary minerals play a catabolic role in **energy metabolism**. Magnesium, for example, is a required **cofactor** for enzymes involved in anaerobic and aerobic energy metabolism including glycolysis and oxidative phosphorylation. A number of enzymes, hormones and cell-signaling molecules depend on phosphorylation for activation, thus, dietary phosphorus is also functional in converting chemical to mechanical energy. Manganese also supports enzymatic functions critical to energy metabolism, including as a critical **co-enzyme** in the synthesis of cholesterol and fatty acids. Iron and sulfur-containing cytochromes are also critical in energy metabolism as electron carriers in the respiratory chain. Cytochrome *c* oxidase is a multi-subunit enzyme in mitochondria that catalyzes the reduction of O_2 to H_2O, which establishes a high energy proton gradient required for adenosine triphosphate **(ATP) synthesis**. This copper enzyme is particularly abundant in tissues of greatest metabolic activity including the heart, brain, and liver.

Several minerals, including chromium, calcium and zinc are catalytic in that they facilitate **hormonal** function. Chromium, for instance, is essential for glucose tolerance factor (GTF), which enhances insulin function. It is also vital for proper carbohydrate metabolism and regulation of blood sugar levels. Although not a hormonal function, zinc's association with **immunity** is also attributed, in part, to its enhanced binding of tyrosine kinase to T-cell receptors (i.e., CD4 and CD8α) that are required for T-lymphocyte development and activation.

6.4 Homework 1

Homework • Answered

Touch the set of structural minerals that are integrated into bone protein, hydroxyapatite

✓ Correct!

Targets placed: 1/1

Undo Delete selected Remove All

You can place up to 1 targets

Answered - Correct!

No attempts left

6.4 Homework 2
Homework • Answered

Touch the set of vitamins that are most involved with cellular gene expression?

✓ Correct!

Targets placed: 1/1

Undo Delete selected Remove All

You can place up to 1 targets

Answered - Correct!

1 attempt left Retry

6.5 Mineral Status Measures

For many dietary minerals, Americans' average intake is adequate to meet the daily allowance, but within the upper limit levels. The overall risk of deficiency for these minerals is low as they are either adequately provided in the typical diet, endogenously recycled, or regulated by internal feedback mechanisms that affect absorption and retention. For other minerals, dietary intake may adversely impact overall mineral status, and for those minerals, Americans are at higher risk of deficiency. The minerals most sensitive to dietary intake levels are **iron, zinc, calcium** and **potassium.**

Mineral Deficiencies

Iron deficiency causes a condition of the blood that reduces oxygen carrying and physical work capacity, called anemia. While reduced work capacity is a characteristic symptom the condition, an individual's iron status cannot be assessed by such a functional measure, like in the case of Vitamin A and its functional vision tests. With iron, there is more variability in the level of dietary iron restriction that elicits the stages of iron deficiency. In the initial stages of inadequate iron intake, hemosiderin and ferritin iron stores are depleted, but without limitations in the supply of iron to the erythrocyte compartment. When stores are depleted, in the early functional iron deficiency stage, erythropoiesis is limited, but not reduced sufficiently to cause measurable anemia. In full, stage three iron deficiency anemia, there is a measurable deficit in the functional erythrocyte compartment, and as a result, red blood cells do not contain an adequate amount of heme-iron. These abnormal blood cells appear under a microscope microcytic (small) and hypochromic (pale), and when separated by centrifugal forces, lower in volume; a condition clinically termed **low hematocrit.** Serum ferritin is the most sensitive indicator of iron storage. The concentration of serum ferritin is proportional to the size of body iron stores in healthy individuals and is estimated in a proportion around 1 µg/L of serum ferritin per 8 mg of storage iron. Total iron-binding capacity (TIBC) is the total quantity of iron that bound to transferrin after the addition of exogenous iron to plasma. TIBC is elevated (> 400 µg/dL) above normal levels with storage iron depletion and is used as an indicator of inadequate iron delivery to erythropoietic tissues.

Low blood calcium is not caused by low dietary intake. Thyroid dysfunction is the primary cause of **low blood calcium**; this is especially true when dietary calcium intake is low, as when thyroid function is normal, PTH stimulates an increase in bone resorption to maintain serum calcium. Other causes of hypocalcemia include chronic kidney failure, vitamin D deficiency, and low blood magnesium levels which may impair the responsiveness of osteoclasts to PTH.

An estimated 2 billion people worldwide are affected by mild dietary **zinc deficiency**. The lack of a sensitive and specific indicator of marginal zinc deficiency hinders the scientific study of its health implications. The symptoms of severe zinc deficiency were identified in studies to learn about acrodermatitis enteropathica, a genetic disorder resulting from the impaired uptake and transport of zinc. Before the cause of this rare condition was known, patients typically died in infancy, but now, with oral zinc therapy, individuals have complete remission of symptoms with indefinite zinc feeding. The symptoms of severe zinc deficiency include the slowing or cessation of growth and development, delayed sexual maturation, characteristic skin rashes, chronic and severe diarrhea, immune system deficiencies, impaired wound healing, diminished appetite, impaired taste sensation, night blindness, swelling and clouding of the corneas, and behavioral disturbances. Zinc deficiency has been studied as one of the contributing aspects to eating disorders such as anorexia nervosa and bulimia, as zinc deficiency and anorexia nervosa have a comparable negative effect on the sense of taste and smell. Zinc supplements are known to stimulate appetite and improve food intake with people who have eating disorders. Although dietary zinc deficiency is unlikely to cause severe zinc deficiency in individuals without a genetic disorder, zinc malabsorption, or conditions of increased zinc loss, such as severe burns or prolonged diarrhea, may also result in severe zinc deficiency. Severe zinc deficiency can also occur in individuals undergoing total parenteral nutrition without zinc, and in those who abuse alcohol. For copper, magnesium, and phosphorus, deficiency is unlikely except in a certain set of conditions, or diseases.

When magnesium is restricted from the diet experimentally, the earliest change is **hypomagnesemia** (ie., low blood magnesium) Over time, serum calcium levels also began to decrease (hypocalcemia) despite adequate dietary calcium, as well as compensatory increased parathyroid hormone (PTH) secretion. Since PTH elevations result in the mobilization of calcium from bone for normalization of blood calcium levels, as magnesium depletion progresses, bone resorption increases and bone density is compromised. Indications of a severe magnesium deficiency also include low blood potassium (i.e., hypokalemia), sodium retention, neuromuscular symptoms (i.e., muscle spasms), loss of appetite, nausea, and vomiting, and even personality changes. The net effect of the electrolyte imbalances may result in a fall in blood pressure (hypotension) that lead to muscle weakness and difficulty breathing.

Copper deficiency indicators include **hypocupremia**, as well as reduced ceruloplasmin concentration (30%), and erythrocyte superoxide dismutase activity. One of the most common clinical signs of copper deficiency is anemia that is unresponsive to iron therapy but corrected by copper supplementation. Copper deficiency may lead to abnormal white blood cell (neutrophil) division, a condition that may be accompanied by increased susceptibility to infection. Physiologic consequences resulting from long-term copper deficiency also may cause defects in connective tissue that lead to vascular and skeletal problems, anemia that persists with copper re-feeding, and possibly specific aspects of central nervous system dysfunction.

Inadequate phosphorus intake is rare, as phosphorus is so widespread in food. In instances where phosphorus intake is low, serum phosphorus levels are not highly affected because renal phosphorus reabsorption increases to compensate. The effects of moderate to severe **hypophosphatemia**, may include loss of appetite, anemia, muscle weakness, bone pain, and osteomalacia, increased susceptibility to infection, numbness and tingling of the extremities, difficulty walking, and respiratory failure. Severe hypophosphatemia may occasionally be life-threatening.

Mineral Excesses

Adverse effects of **excess** intake for most minerals have not been identified from levels occurring naturally in food. However, for some minerals, that are added to foods for non-nutritional purposes, or supplemental and therapeutic level doses, have been shown to have adverse effects.

The major adverse effect of **hypernatremia** is elevated blood pressure, which has been shown to be an etiologically related risk factor for cardiovascular and renal diseases. Salt-sensitive individuals such as those genetically pre-dispositioned and of certain races (i.e., African Americans) tend to be more sensitive to the blood pressure-raising effects of sodium chloride intake than their Caucasian counterparts. There is considerable evidence that salt sensitivity is modifiable, and partially mitigated with increased dietary potassium. **Hyperkalemia** typically occurs only in instances where potassium excretion is impaired, that require use of common drugs that can substantially impair potassium excretion, such as angiotensin-converting enzyme (ACE) inhibitors, angiotensin receptor blockers (ARB), and potassium-sparing diuretics.

Magnesium that is used in magnesium salts in laxatives and antacids can lead to severe **hypermagnesemia** if intake exceeds the tolerable upper intake level of 350 mg per day. Since food alone poses no risk for toxicity, the UL for magnesium only includes supplemental magnesium intake. Excessive intake of zinc can lead to secondary copper deficiency in individuals using zinc supplements or high levels of zinc-enriched dental creams.

Hyperphosphatemia may affect individuals with inappropriately low parathyroid hormone (PTH) levels (hypothyroidism) as they lack PTH stimulation of renal phosphate excretion and fail to stimulate synthesis of 1,25-dihydroxyvitamin D (the active form of vitamin D). These individuals cannot excrete excess phosphorus in the absence of these hormones. Elevated serum phosphorus concentrations have been associated with accelerated disease progression in individuals with impaired kidney function and have been linked to increased risk of adverse health outcomes in the general population.

Zinc supplements are advocated for the treatment of common colds in adults, as it may reduce the duration of cold symptoms. While evidence to support this notion is lacking, it is established that taking zinc lozenges every two to three hours during waking hours, often results in daily zinc intakes well above the tolerable upper intake level of 40 mg/day and acute **hyperzincemia**. In the short-term (e.g., less than five days), zinc intake at that level has not resulted in serious side effects, however, with the use of zinc lozenges for prolonged periods (e.g., 6-8 weeks) is likely to result in copper deficiency. For this reason, many zinc containing medications recommended that a person who does not show clear evidence of improvement of cold symptoms after three to five days of zinc lozenge use seek medical evaluation. Hyperparathyroidism is the most common cause of high serum calcium levels.

Hypercalcemia has not been associated with consuming high amounts of natural calcium from foods; however, it may be related to the consumption of large quantities of calcium supplements, in combination with antacids, (i.e., calcium carbonate), and sodium bicarbonate (absorbable alkali). This condition is termed Calcium-Alkali Syndrome (formerly known as Milk-Alkali Syndrome) and has been associated with calcium supplement levels from 1.5 to 16.5 g/day for 2 days to 30 years. Mild hypercalcemia may be without symptoms or may result in loss of appetite, nausea, vomiting, constipation, abdominal pain, fatigue, frequent urination (polyuria), and hypertension. More severe hypercalcemia may result in confusion, delirium, coma, and if not treated, even death.

6.5 Homework 1

Homework • Answered

Match each mineral to the disease, symptom or condition that could exacerbate in periods of prolonged restricted intake or deficiency.

Premise		Response
1 Iron	→	C Anemia
2 Calcium	→	A Low bone mass
3 Zinc	→	B dermatitis

Answered - Correct!

1 attempt left Retry

6.5 Homework 2

Homework • Answered

Which two minerals do NOT have a defined Upper Limit for daily intake?

- (selected) **A** Potassium and chromium
- **B** Sodium and chloride
- **C** Iron and chromium
- **D** Potassium and iron

Explanation

Correct, Potassium and Chromium do NOT have an upper limit

Answered - Correct! 1 attempt left Retry

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