Vitamins, Minerals, and Metabolism

Food sources of Riboflavin (vitamin B2):
Cereal, nuts, milk, eggs, green leafy vegetables and lean meat

March 2014
Fat-Soluble and Water-Soluble Vitamins

Vitamin D is fat-soluble (hydrophobic) and vitamin C is water-soluble.

Based on that, which of these would you expect to leave the bloodstream in the urine, and which would you expect to stay inside the body for longer? Why?

Given that answer, do you hypothesize that it would be easier to overdose on vitamin C or on vitamin D? Why?
## Vitamins vs. Minerals

<table>
<thead>
<tr>
<th>Vitamins</th>
<th>Minerals</th>
</tr>
</thead>
<tbody>
<tr>
<td>Organic, contain carbon</td>
<td>Inorganic, non-carbon chemicals – on periodic table</td>
</tr>
<tr>
<td>Assist enzyme function</td>
<td>Can assist enzyme function and/or build structures, such as bones</td>
</tr>
<tr>
<td>Fat- or water-soluble</td>
<td>Eaten in charged, water-soluble/bound form</td>
</tr>
<tr>
<td>May not be absorbed well unless other substances help</td>
<td>May not be absorbed well unless other substances help</td>
</tr>
<tr>
<td>Micronutrients; needed in small amounts</td>
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</tbody>
</table>
Classify the following as vitamins or minerals:

- Niacin
- Calcium
- Iron
- Thiamine
- Phosphorus
- Cyanocobalamin
Fat-Soluble vs. Water-Soluble Vitamins

- Fat-soluble vitamins are generally stored in the liver; water-soluble vitamins are generally lost in urine. *Cooking in oil* leaches out fat-soluble vitamins, and *boiling in water* leaches out water-soluble vitamins!

<table>
<thead>
<tr>
<th>Fat-Soluble</th>
<th>Water-Soluble</th>
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</thead>
<tbody>
<tr>
<td>Vitamin A</td>
<td>Vitamin C</td>
</tr>
<tr>
<td>Vitamin D</td>
<td>Most B vitamins</td>
</tr>
<tr>
<td>Vitamin E</td>
<td></td>
</tr>
<tr>
<td>Vitamin K</td>
<td></td>
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</tbody>
</table>
Vitamin A

- A group of fat-soluble substances called retinoids. Often found in orange/red vegetables as a provitamin, which our body converts into retinoic acid.

- Retinoic acid is needed to make light receptors in the retina of the eye. Lack of can lead to night blindness or flash blindness. Chronic lack of Vitamin A can even lead to retinal damage (macular degeneration.)

- Excessive doses of vitamin A can cause liver damage or changes in skin color. During pregnancy, excessive vitamin A supplements or drugs can lead to birth defects.
Vitamin D

• Fat-soluble steroid vitamin that is made in skin under sunlight.

• Needed for efficient calcium absorption in the small intestine; often added to fortified milk, but is absorbed best with lipids. Lack of Vitamin D = higher risk of bone disease.

• Excessive vitamin D can lead to liver damage and kidney stones from excess calcium deposits.

• Good sources include liver, eggs, some lichens, and some fungi. Vegans may need to supplement, though severe deficiency is rare in sunny climates.
Vitamin E

- Fat-soluble vitamin that acts as an antioxidant, preventing damage to membranes by free radicals. Free radicals are molecules with an unpaired (extra/missing) electron, which can be passed on to other molecules, leading to a chain reaction that damages cells. Free radicals are a normal product of respiration.
- Also needed for optimal nerve transmission along the axon.
- Deficiency is very rare. Overdose can cause excessive bleeding.
- Sources include wheat germ and avocados.
Vitamin K

- Fat-soluble vitamin that is normally made by gut bacteria and is important for blood clotting. Deficiency is rare except in infants who have not yet grown gut bacteria.
- Needed for *thrombin* function. Thrombin is a clotting protein that converts the protein *fibrinogen* into *fibrin*, activating the formation of a blood clot.
Vitamin C

• Ascorbic acid, a water-soluble vitamin that acts as an antioxidant and helps make collagen, a protein in your soft tissues.

• Found in sour fruits such as oranges, pineapples, and cranberries, as well as some animal products. (Most mammals make their own vitamin C, except for us.)

• Lack of vitamin C causes scurvy, a disease that leads to gum damage, bleeding, joint pain, fatigue, and eventually death.

• It is difficult to overdose on vitamin C, but taking regular megadoses can increase the risk of kidney stones.
Does Vitamin C Cure Colds?

- No.
B Vitamins

- Although B vitamins are grouped together, and many (such as B1, B2, and B3) can be found in similar foods, they are chemically different from each other and have distinct roles. Instead of memorizing the numbers, focus on their function.

Vitamin B1: Thiamine
Vitamin B2: Riboflavin  \[\text{Needed to make ATP}\]
Vitamin B3: Niacin

Also needed for healthy axons.

Vitamin B9: Folic Acid
Vitamin B12: Cobalamin  \[\text{Needed to make healthy red blood cells}\]
ATP: Harnessing Energy

- ATP (Adenosine triphosphate) is a molecule that “carries” usable energy around the cell in all living things. Everything from DNA-making enzymes to the proteins that contract your muscles depends on ATP!

- ATP is made of a modified DNA base (adenosine) with three phosphate (phosphorus + oxygen) groups attached.

- Removing one of these phosphate groups turns ATP into ADP and releases energy. To store energy, we add a phosphate group to ADP to make ATP again.

![Diagram of the ATP-ADP Cycle](image-url)
Vitamins + Making ATP

• We use oxygen to pull electrons from food to harvest energy. To break down glucose, we use three phases: glycolysis (breaks it into two pieces), the Krebs cycle (releases carbon dioxide), and the electron transport chain (uses oxygen to make a lot of ATP).

• Niacin is needed to make NADH, which carries electrons from glycolysis and the Krebs cycle into the electron transport chain. (see diagram, next slide)

• Riboflavin is needed to make FADH$_2$, which has a similar role to NADH.

• Thiamine is needed to make acetyl CoA, the 2-carbon piece of sugar that goes into mitochondria.
Glucose $\xrightarrow{glycolysis}$ Pyruvate

- A little ATP
- NADH

Acetyl CoA $\xrightarrow{Beta oxidation}$ Fat

Kreb’s cycle

- Some ATP
- NADH
- FADH$_2$

Electron transport chain

- Oxygen

Mitochondrion

- Lots of ATP
- Water

Carbon chain processing is in red.
Electron carriers in blue.
A Public Health Problem

In the early twentieth century, many people in the American South suffered from a niacin deficiency called pellagra. This illness, which could lead to diarrhea, dermatitis, dementia, and death (the 4 D’s), was the result of an unbalanced diet of grits and fatback, with white flour used in bread. Since white flour was missing the wheat germ, there was little or no niacin in it.

Pellagra is no longer a major problem in the US, and the solution the government enforced was extremely cheap and effective.

What might be a very cheap way to prevent people from getting pellagra without requiring them to actually take vitamin pills?
Enrichment vs Fortification

• An enriched food is one in which vitamins/minerals lost during processing are added back in. Example: Since 1942, it has been mandated that bleached, milled wheat flour in the US be enriched with B vitamins to prevent pellagra.

• A fortified food is one in which vitamins/minerals are added that are not naturally present. For example, orange juice may be fortified with calcium to make up for the fact that children could drink it as a milk substitute.
The Electron Transport Chain (oxidative phosphorylation) uses oxygen and NADH/FADH₂ to make ATP. This step produces the most ATP. Oxygen is turned into water, and NADH and FADH₂ are recycled for later use.

The NADH and FADH₂ provide high energy electrons, which are used to pump H⁺ ions. These ions then diffuse back across, and their diffusion spins an ATPase enzyme like a waterwheel, making ATP from ADP!

Free radicals are made when this process of electron transfer happens *incompletely*. Free radical damage is an expected result of respiration!
Another Diagram (Same Pathway, without Fat)

**Process: Overview of Cellular Respiration**

1. **Glycolysis**
   - Glucose → Pyruvate (two for every glucose) → ATP
   - ATP

2. **Pyruvate Processing**
   - Pyruvate → Acetyl CoA → CO₂

3. **Citric Acid Cycle**
   - NADH FADH₂ → ATP (or GTP)
   - CO₂

4. **Electron Transport and Chemiosmosis**
   - Electron transport chain establishes proton gradient that is used to produce ATP
   - O₂ → H₂O
   - ATP

What goes in:

What comes out:

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Microminerals vs. Macrominerals

• Your text emphasizes the difference between microminerals (of which you need less than 100 mg/day) and macrominerals (of which you need more than 100 mg/day).

• However, I do not emphasize this distinction because...
  • It is possible to be deficient in macro- or microminerals!
  • Even “microminerals” may be hard to absorb from certain food sources. Iron is a micromineral, yet iron deficiency is common!
Some Dietary Minerals

- Potassium (electrolyte covered last chapter)
- Sodium (electrolyte covered last chapter)
- Chloride (electrolyte covered last chapter)
- Calcium
- Iron
- Magnesium
- Zinc
- Selenium
- Copper
- Fluoride
- Phosphorus
- Iodine
- Manganese, bromide, etc.
Bones

- Bones are *living structures* consisting of hard, calcified connective tissue, spongy bone, and soft marrow. They do more than provide support. Bone marrow makes our blood cells!

- The hard parts of bone are made of calcium phosphate. You need *calcium* and *phosphorus* to make this mineralized substance. The soft parts are made of *collagen* protein and live cells.

- The cells that build up bone are called *osteoblasts*. The cells that break down bones are called *osteoclasts*. The regions where bones grow (at least after early development) are called *growth plates*. 
Osteoporosis

• With age, bones may be broken down by osteoclasts more than they are built up by osteoblasts, especially when calcium or vitamin D intake is low or thyroid and parathyroid signaling is poor.

• About 1 in 2 women and 1 in 4 men over 50 are at serious risk of breaking a bone due to osteoporosis, where the bones become spongy and brittle. Women can lose 20% of their bone density after menopause!

• Even normally harmless falls can become dangerous when bones have been weakened by osteoporosis.

• Some research indicates that excessive consumption of soda containing phosphoric acid increases osteoporosis risk, but this is inconclusive.
Thyroid + Parathyroid Glands

- The thyroid and parathyroid glands, located in the neck, regulate blood calcium, body temperature, and rate of metabolism.

- *Parathyroid hormone* (PTH) activates osteoclasts to break down bone and release calcium into the bloodstream. *Calcitonin* from the thyroid opposes the action of PTH and causes osteoblasts to use more calcium to build bone.

- *Iodine* is needed for proper thyroid function.

(Image source: R. Bowen, Colorado State University)
Dietary Sources of Calcium

- Calcium can be found in dairy products, some green leafy vegetables (kale, broccoli), fortified soy milk, fortified tofu, and some nuts.
- Note that some vegetables, such as spinach, contain antinutrients such as oxalate that reduce calcium absorption.
- Calcium is absorbed best when a meal also contains vitamin D and some lipids.
- Calcium supplements can be taken in different forms (citrate, carbonate, etc). A table in your text lists how effective each of these are as calcium sources.
Phosphorus

• Usually taken into the body as phosphate, \( \text{PO}_4^3^- \), phosphorus can be found in legumes, grains, meat, milk, and even soft drinks (though phosphoric acid in soda may be bad for bones.)

• Phosphorus is needed to make the calcium phosphate in bones, the pieces of DNA, phospholipids, and the energy-storing molecule ATP, which is critical for all living cells. (See next slide)

• Phosphorus deficiency is rare, but can lead to weakness and weak bones/bone pain.
Iron

- Iron is needed to make functional hemoglobin, a protein that carries oxygen in your red blood cells. Without iron, you cannot make enough red blood cells and deliver oxygen to your cells from your lungs. This can result in iron-deficiency anemia. Aside from dietary factors, heavy menstrual flow and pregnancy can also increase risk.

- Symptoms of iron deficiency anemia:
  - Fatigue, shortness of breath, pallor.
Fluoride (Nice Graphic from USA Today using ADA and CDC Data)

**Fluoride in U.S. Water Supply**

Water fluoridation began in the USA in 1945. Both the American Dental Association and the Centers for Disease Control and Prevention say fluoridated water is a safe and cost-effective way to prevent tooth decay.

**1945**

Grand Rapids, Mich., is the first U.S. city to treat its water supply with fluoride.

**1956**

Crest, the first toothpaste with fluoride, is introduced.

**Today**

More than 195 million Americans are on fluoridated water systems, according to the Centers for Disease Control.

**Recommended Concentration to Fight Cavities:**

1 part fluoride per million parts water

**More than 72 percent** of Americans have access to fluoridated water.

**It costs about 50 cents** per person per year to add fluoride in larger cities.

**Reduces tooth decay 20–40 percent**

Sources: American Dental Association, Centers for Disease Control and Prevention.

Graphic by Kevin A. Kepple, Anne Carey, USA TODAY.
Iodine

- Iodine, found in seawater, iodized salt, seafood, and some root vegetables (with skin on) is used by the thyroid gland to make hormones, such as thyroxin, that regulate metabolism and body temperature.
- Lack of iodine can lead to goiter, a swelling of the thyroid glands. In children, lack of iodine can harm brain development. Overdose can lead to severe nausea and even coma.
- Iodine supplements are sometimes used to prevent radiation sickness following certain exposures.
- Thanks to the addition of iodine to sale, iodine deficiency is rare in the US. Those on very low-sodium diets may consider supplementing.
Magnesium

- Magnesium is important to make DNA and RNA, which carry the information needed to make proteins. It is also needed to make ATP, the main energy-carrying molecule of the cell.
- Magnesium is also needed to relax muscles after they contract. This is why magnesium deficiencies can cause cramping. Overdose is dangerous, too – especially to people with kidney trouble!
- The body needs only trace amounts of magnesium, which can be easily gotten in fresh veggies and whole-grain breads. Although severe deficiency is rare outside of patients with alcoholism, 50-75% of Americans get less magnesium in their diet than they should! The best solution is to eat more fresh greens and whole grains.
Zinc

• Needed to break down alcohol, but also a cofactor to many enzymes that copy and read DNA. (“Zinc-fingers” are regions of protein that stick to DNA and help copy its code. The positively charged zinc helps fold the protein tightly around the DNA double helix. In figure at lower right, zinc is green, protein is blue w/ red arrows, DNA is orange.

• Deficiency more common in adolescents and children, and can lead to growth and mental disabilities. Antinutrients in some forms of flour can prevent zinc from being absorbed.

• Sources include meat, eggs, legumes, and whole grains. Refined grains lose zinc, and it is easier to absorb zinc from meat.
Other Microminerals

Copper
Needed to process iron; rare deficiencies lead to anemia. Deficiency rare, but copper may help heart health.

Selenium
Antioxidant. Some roles in thyroid + heart health. Toxic in anything but very small amounts!

Chromium
Helps the body respond to insulin signals. Found in nuts, whole grains, liver, cheese.