Chapter 13: Electrolyte Micronutrients

In this chapter, electrolytes will be explained before learning more about the 4 electrolyte micronutrients. Then, hypertension will be discussed, along with the impact of these micronutrients on the condition.

Subsections:

13.1 Electrolytes
13.2 Sodium
13.3 Chloride
13.4 Potassium
13.5 Magnesium
13.6 Hypertension, Salt-Sensitivity & the DASH Diet

13.1 Electrolytes

Electrolytes are compounds that separate into ions (molecules with a charge) in water. These compounds are also commonly referred to as salts. Electrolytes can be separated into 2 classes:

Cations: ions that have a positive charge
Anions: ions that have a negative charge

The following table summarizes the major intracellular and extracellular electrolytes by giving their milliequivalents (mEq)/L. Milliequivalents are a measure of charge. Thus, a higher value means that the cation or anion is accounting for more charge.

Table 13.11 Major intracellular and extracellular electrolytes

<table>
<thead>
<tr>
<th>Intracellular</th>
<th>Extracellular</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cations</td>
<td>Anions</td>
</tr>
<tr>
<td>Potassium (K⁺)</td>
<td>Phosphate (PO₄⁻)</td>
</tr>
<tr>
<td>Magnesium (Mg²⁺)</td>
<td>Proteins</td>
</tr>
<tr>
<td></td>
<td>Sulfate (SO₄²⁻)</td>
</tr>
</tbody>
</table>
The following figure graphically shows the major intracellular and extracellular cations (green) and anions (red).

Figure 13.11 Major intracellular and extracellular cations (green) and anions (red)

Electrolytes and proteins are important in fluid balance. Your body is 60% water by weight. Two-thirds of this water is intracellular, or within cells. One-third of the water is extracellular, or outside of cells. One-fourth of the extracellular fluid is plasma, while the other 3/4 is interstitial (between cells) fluid. Thus, when considering total body water, around 66% is intracellular fluid, 25% is interstitial fluid, and 8% is plasma.

You might remember the term “osmosis” from a past science course. You might remember that osmosis has something to do with the movement of water across membranes; into or out of cells. You might further remember that osmosis can be driven by solute concentration (the concentration of dissolved substances). The solute concentration that drives osmosis is commonly called osmolality. Very simply, osmolality is the concentration of a dissolved substance, which tends to affect the movement of water. The electrolytes shown in the diagram above are responsible for osmolality. In Figure 13.11, a higher concentration of ions and proteins in the cell would be osmolality, that would ultimately drive the movement of water into the cell. If the concentration of ions and proteins outside of the cells were greater, you would expect that the osmolality would drive the movement of water out of the cell. Water balance in our bodies takes place everywhere...in all of our organs...all of our tissues...between our individual cells, in a great complex of interactions ultimately moderated by osmolality. Osmolality can drive water movement into and out of tissues and cells, and osmolality can hold water in a particular place.

Fluid distribution between the different compartments of the body are shown in Figure 13.12.
13.2 Sodium

Salt (NaCl) contributes almost all the sodium that we consume. 75-85% of the salt we consume is from processed foods, 10% is naturally in foods, and added salt contributes 10-15% of total salt intake. Sodium is the major cation in extracellular fluid.

95-100% of consumed sodium is absorbed. Sodium is taken up into the enterocyte through multiple mechanisms before being pumped out of the enterocyte by sodium-potassium (Na⁺/K⁺) ATPase. Sodium-potassium ATPase is an active carrier transporter that pumps 3 sodium ions out of the cell and 2 potassium ions into the cell, as shown below.

References & Links
Figure 13.21 Sodium-potassium ATPase (aka sodium-potassium pump), an active carrier transporter

Sodium has 3 main functions:
1. Fluid balance
2. Aids in monosaccharide and amino acid absorption
3. Muscle contraction and nerve transmission (will not discussed in this chapter however)

**Fluid balance**
The body regulates sodium and fluid levels through a series of processes as shown in Figure 13.22. A decrease in plasma volume and blood pressure signals the kidney to release the enzyme renin. Renin activates angiotensin that is converted to angiotensin II. Angiotensin II signals the adrenal glands to secrete the hormone aldosterone. Aldosterone increases sodium reabsorption in the kidney, thus decreasing sodium excretion. These actions cause plasma sodium concentrations to increase, which is detected by the hypothalamus. The hypothalamus stimulates the pituitary gland to release antidiuretic hormone (ADH) that causes the kidneys to reabsorb water, decreasing water excretion. The net result is an increase in blood volume and blood pressure.
Aids in monosaccharide and amino acid absorption

Glucose and galactose are taken up into the enterocyte by sodium-glucose cotransporter 1 (SGLT1), which requires sodium to be transported along with glucose or galactose.

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**Figure 13.22 Response to decreased plasma volume and blood pressure**

**Figure 13.23 Carbohydrate Absorption**
Amino acids are taken up and transported into circulation through a variety of amino acid transporters. Some of these transporters are sodium-dependent (require sodium to transport amino acids).

![Protein absorption diagram](image)

Figure 13.24 Protein absorption

Sodium deficiency is rare, and is normally due to excessive sweating. Sweat loss must reach 2-3% of body weight before sodium losses are a concern\(^1,2\). This situation can occur in marathon runners and ultra-marathon runners who sweat for many hours straight (without proper liquid intake). Low blood sodium levels (hyponatremia) can result in\(^1\):

- Headache
- Nausea
- Vomiting
- Fatigue
- Muscle Cramps

Hyponatremia can also result from **water intoxication**, a potentially fatal situation that can arise when too much water is consumed at one time. A decrease in sodium concentration can reduce osmolality outside of the cells and, therefore, increase the relative osmolality inside of the cells. As a consequence, cells swell as water moves in. This is a particularly dangerous situation in the brain. Swelling of brain tissue can result in an increase in intracranial pressure that can ultimately lead to cerebral edema and brainstem dysfunction.\(^4\)

Sodium is not toxic, but higher sodium intake increases the risk of developing high blood pressure. High sodium intake also increases calcium excretion, but studies haven't found an increased risk of osteoporosis. High sodium intake may also increase the risk of developing kidney stones (by increasing calcium excretion), because calcium oxalate is the most common form of kidney stone as reference in Chapter 9\(^1\).
13.3 Chloride

Sodium's partner in salt, chloride, is the major extracellular anion. Almost all of the chloride we consume is from salt, and almost all chloride is absorbed. It is excreted in urine like sodium.

Chloride has the following functions\(^1\):

1. Aids in nerve impulses
2. Component of HCl
3. Released by white blood cells to kill foreign substances
4. Helps maintain acid-base balance

Chloride deficiency is rare, but can occur because of severe diarrhea or vomiting. Other symptoms of this deficiency include\(^1,2\):

- Weakness
- Diarrhea and vomiting
- Lethargy

Chloride is not toxic, but since it is a part of salt, it is recommended that we restrict our intake to avoid potential increases in blood pressure.

References & Links
13.4 Potassium

Potassium is the major intracellular cation. Good sources of potassium include beans, potatoes (with skin), milk products, orange juice, tomato juice, and bananas\textsuperscript{1,2}. Potassium, like sodium and chloride, is well absorbed. Greater than 85% of consumed potassium is absorbed. Potassium is primarily excreted in urine (~90\%)\textsuperscript{3}.

Potassium is important for:

1. Fluid Balance
2. Nerve transmission and muscle contraction

Increased potassium intake results in decreased calcium excretion. This is the opposite effect of increased sodium intake, which increases calcium excretion\textsuperscript{1}.

Potassium deficiency is rare but can be fatal. Symptoms include:

- Weakness
- Fatigue
- Constipation
- Irregular heartbeat (can be fatal)

Deficiency can occur in individuals that are on diuretics, drugs that increase urine production, and individuals with eating disorders\textsuperscript{1}.

Toxicity is also extremely rare, only occurring if there is a problem with kidney function. Symptoms of toxicity are irregular heartbeat and even cardiac arrest\textsuperscript{1}.

References & Links
Magnesium is an electrolyte, but that is not considered its major function in the body. Green leafy vegetables, beans, nuts, seeds, and whole grains are good sources of magnesium. 40-60% of consumed magnesium is absorbed at normal levels of intake. Magnesium is excreted primarily in urine.

55-60% of magnesium in the body is found in bone. Some (30%) of this bone magnesium is believed to be exchangeable, or can be used to maintain blood concentrations, similar to how calcium in bones can be used to maintain blood concentrations.

Magnesium helps to stabilize ATP and nucleotides by binding to phosphate groups. Magnesium plays a role in over 300 enzymes in the body. Here is a list of some of the physiological processes that magnesium participates in:

- Glycolysis
- TCA cycle
- Fatty acid oxidation (beta-oxidation)
- DNA and RNA transcription
- Nucleotide synthesis
- Muscle contraction

Magnesium deficiency is rare, but can be caused by prolonged diarrhea or vomiting. Symptoms include:

- Irregular heartbeat
- Muscle spasms
- Disorientation
- Seizures
- Nausea
- Vomiting

Magnesium toxicity is also rare but can occur from excessive use of antacids or laxatives. Symptoms include:

- Diarrhea
- Nausea
- Flushing
- Double vision
- Slurred speech
Magnesium supplements differ in percent of magnesium in the different forms, as shown in Figure 13.51.

Figure 13.51 Percent magnesium in oral supplements

The bioavailability of magnesium oxide is significantly lower than magnesium chloride, magnesium lactate, and magnesium aspartate. The latter 3 are equally bioavailable.

References & Links
13.6 Hypertension, Salt-Sensitivity & the DASH Diet

Approximately 27% of American adults have hypertension (high blood pressure), which increases their risk of developing cardiovascular disease. Salt and/or sodium intake is believed to be a major causative factor in the development of hypertension. However, it is now known that not everyone is salt-sensitive. Salt-sensitive means that a person’s blood pressure increases with increased salt intake and decreases with decreased salt intake. Approximately 25% of normotensive (normal blood pressure) individuals and 50% of hypertensive individuals are salt-sensitive. Most others are salt-insensitive, and in a small portion of individuals, low salt consumption actually increases blood pressure. Unfortunately, there isn't a clinical method to determine whether a person is salt-sensitive. There are some known characteristics that increase the likelihood of an individual being salt-sensitive. They are:

- Elderly
- Female
- African-American
- Hypertensive
- Diabetic
- Chronic Kidney Disease

There is some evidence now suggesting that there may be negative effects in some people who restrict their sodium intakes to the levels recommended by some organizations. The second link describes a couple of studies that had conflicting outcomes as it relates to the importance of salt reduction in decreasing blood pressure and cardiovascular disease. The third link is to a study that found that higher potassium consumption, not lower sodium consumption, was associated with decreased blood pressure in adolescent teenage girls.

Required Web Links

Report Questions Reducing Salt Intake Too Dramatically
For Teenagers, Potassium May Matter More Than Salt

To combat hypertension, the Dietary Approaches to Stop Hypertension (DASH) diet was developed. This diet emphasizes fruits, vegetables, fat-free/low-fat milk and milk products, whole grain products, fish, poultry, and nuts. It limits red meat, sweets, added sugars, and sugar-containing beverages. As a result, the diet is high in potassium, magnesium, calcium, protein, and fiber.
The daily goals for the DASH diet are shown in Figure 13.61.

**BOX 2**

**Daily Nutrient Goals Used in the DASH Studies**
(for a 2,100 Calorie Eating Plan)

<table>
<thead>
<tr>
<th>Nutrient</th>
<th>Goal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total fat</td>
<td>27% of calories</td>
</tr>
<tr>
<td>Saturated fat</td>
<td>6% of calories</td>
</tr>
<tr>
<td>Protein</td>
<td>18% of calories</td>
</tr>
<tr>
<td>Carbohydrate</td>
<td>55% of calories</td>
</tr>
<tr>
<td>Cholesterol</td>
<td>150 mg</td>
</tr>
<tr>
<td>Sodium</td>
<td>2,300 mg*</td>
</tr>
<tr>
<td>Potassium</td>
<td>4,700 mg</td>
</tr>
<tr>
<td>Calcium</td>
<td>1,250 mg</td>
</tr>
<tr>
<td>Magnesium</td>
<td>500 mg</td>
</tr>
<tr>
<td>Fiber</td>
<td>30 g</td>
</tr>
</tbody>
</table>

* 1,500 mg sodium was a lower goal tested and found to be even better for lowering blood pressure. It was particularly effective for middle-aged and older individuals, African Americans, and those who already had high blood pressure. g = grams; mg = milligrams

Figure 13.61 DASH daily nutrient goals³

To get an idea of what types of foods and how much would be consumed in the diet, an eating plan is shown in Figure 13.62.
The DASH diet has been shown to be remarkably effective in decreasing blood pressure in those with hypertension. Nevertheless, most people with hypertension aren't following the DASH diet. In fact, evidence from the National Health and Nutrition Examination Survey found that significantly fewer hypertensive individuals were following the DASH diet in 1999-2004 than during 1988-1994, as shown in the Table 13.61.
Table 13.61 Percent of hypertensive subjects in NHANES trial meeting the DASH goals

<table>
<thead>
<tr>
<th>Variable</th>
<th>NHANES 1988-1994 (n = 4336)</th>
<th>NHANES 1999-2004 (n = 3821)</th>
<th>Absolute Change (%)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>DASH Accordance</td>
<td>29.3 ± 1.5</td>
<td>21.7 ± 1.3</td>
<td>-7.6</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Total Fat</td>
<td>42.9 ± 1.8</td>
<td>35.9 ± 2.0</td>
<td>-7.0</td>
<td>0.01</td>
</tr>
<tr>
<td>Saturated Fat</td>
<td>20.6 ± 1.2</td>
<td>20.4 ± 1.4</td>
<td>-0.2</td>
<td>0.94</td>
</tr>
<tr>
<td>Protein</td>
<td>43.7 ± 2.0</td>
<td>47.7 ± 1.9</td>
<td>4.0</td>
<td>0.73</td>
</tr>
<tr>
<td>Cholesterol</td>
<td>26.4 ± 2.2</td>
<td>24.3 ± 1.6</td>
<td>-2.1</td>
<td>0.44</td>
</tr>
<tr>
<td>Fiber</td>
<td>20.2 ± 1.5</td>
<td>12.3 ± 0.9</td>
<td>-7.9</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Magnesium</td>
<td>14.2 ± 1.3</td>
<td>6.4 ± 0.8</td>
<td>-7.8</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Calcium</td>
<td>19.0 ± 1.6</td>
<td>17.6 ± 2.0</td>
<td>-1.4</td>
<td>0.58</td>
</tr>
<tr>
<td>Potassium</td>
<td>12.7 ± 0.9</td>
<td>11.7 ± 0.9</td>
<td>-1.0</td>
<td>0.46</td>
</tr>
<tr>
<td>Sodium</td>
<td>17.8 ± 1.5</td>
<td>14.6 ± 1.3</td>
<td>-3.2</td>
<td>0.21</td>
</tr>
</tbody>
</table>

The main components that contributed to the decrease in DASH diet accordance were total fat, fiber, and magnesium, as indicated by their high negative absolute changes.

**References & Links**


**Links**


For Teenagers, Potassium May Matter More Than Salt -
http://well.blogs.nytimes.com/2015/04/27/for-teenagers-potassium-may-matter-more-than-salt/