Biochemistry of Water Soluble Vitamins, Sources, Biochemical Functions and Toxicity

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Abstract

There are thirteen vitamins in humans: four fat soluble (A, D, E, and K) and nine water soluble (vitamin B complex and vitamin C). Water-soluble vitamins dissolve rapidly in water and are usually easily excreted by the body. Because they are not processed too soon, a steady intake is important. B vitamin supplements available for each vitamin: B1: thiamine, B2: riboflavin, B3: niacin, etc. Niacin, pantothenic acid, biotin and folate are recognized by name rather than by quantity. B vitamins are usually used in energy drinks and many are advertised with high levels of B vitamins boasting that they can 'go through the day and do not feel nervous or anxious. B vitamins are primarily absorbed in foods such as pork, fish and liver. Healthy vitamin B sources include vegetables (pulses or beans), whole grains, rice, bananas, chilli pepper, temppeh, brewer's yeast and molasses. While beverage yeast has been used to produce beer, its bioavailability varies from low to adverse, as drinking ethanol hinders the absorption of thiamine (B1), riboflavin (B2), niacin (B3), biotin (B7) and folic acid (B9). Vitamin C is needed for tissue growth and repair in all areas of the body. It is used as an essential protein for the development, repair and maintenance of cartilage, bones and teeth and assists in the absorption of iron.

Keywords: Vitamins, water soluble vitamins, Vitamin C, Vitamin B1, folate.

INTRODUCTION

Vitamins are either water-soluble or fat-soluble. Many vitamins do not exist in individual molecules, but belong to similar classes known as vitamins. Vitamin E, for instance, comprises 4 tocopherols and 4 tocotrienols. There are thirteen vitamins in humans: four fat soluble (A, D, E, and K) and nine water soluble (vitamin B complex and vitamin C). Water-soluble vitamins dissolve rapidly in water and are usually easily excreted by the body. Because they are not processed too soon, a steady intake is important. Fat soluble vitamins are processed through the intestine using lipids (fats). The body can accumulate vitamins A and D that can lead to dangerous hypervitaminosis. Fat-soluble malabsorption vitamin deficiency is especially important in cystic fibrosis [1].

B vitamins are a class of water-soluble vitamins that are important to cell metabolism [2, 3]. Although they have common names, these vitamins are chemically different compounds that coexist in the same food. Eight dietary supplements are generally referred to as vitamin B complexes [4, 5]. The highest concentration of B vitamins can be found in meat. These can also be used in limited quantities in whole unprocessed carbohydrate-dependent foods. The level of vitamin B found in refined carbohydrates, including sugar or white grain, is lower than the amount of natural fuel [6].

Vitamin C is a vital nutrient for some animals, including humans. Vitamin C contains different vitamins that produce vitamin C in animals. Some of the food supplements contain ascorbate salts, including sodium ascorbate and calcium ascorbate. These releases are processed through digestion. Ascorbate and ascorbic acid are naturally found within the body as forms interconverted by pH. Dehydroascorbic acid is converted by reducing agents to ascorbic acid in oxidised molecular forms [7].
Table-1: An overview of water soluble vitamins

<table>
<thead>
<tr>
<th>Vitamin B complex (B1, B2, B3, B5, B6, B7, B9 and B12)</th>
<th>Function</th>
<th>Deficiency</th>
<th>Dietary source</th>
<th>RDA (Adult male/female)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Act as co-enzymes</td>
<td>Mostly cause serious diseases</td>
<td>Meat, vegetable, nuts, eggs, pasta, bread, cereals etc</td>
<td>B1(1.2 mg/1.1 mg) B2(1.3 mg/1.1 mg) B3(16 mg/14 mg) B5(16 mg/14 mg) B6(1.3–1.7 mg/1.2–1.5 mg) B7(30 µg) B9(400 µg) B12(2.4 µg)</td>
<td></td>
</tr>
</tbody>
</table>

Vitamin C


Scurvy

Citrus fruits and vegetables, liver

90 mg/75 mg

Water Soluble Vitamins

Vitamin B

Basic numbers or names of each vitamin are given as individual B vitamin supplements for each vitamin: B1: thiamine, B2: riboflavin, B3: niacin, etc. Niacin, pantothenic acid, biotin and folate are recognised by name rather than by quantity. Each B vitamin is either a cofactor (usually a coenzyme) or a precursor to major metabolic processes [2].

Consequently, following elimination by regulation in different countries (including the United States), B vitamins thiamine, riboflavin, niacin and folic acid must be incorporated into white flour. It is often referred to on food labels as enriched flour. B vitamins are primarily absorbed in foods such as pork, fish and liver. Healthy vitamin B sources include vegetables (pulses or beans), whole grains, rice, bananas, chilli pepper, tempeh, brewer's yeast and molasses. While beverage yeast has been used to produce beer, its bioavailability varies from low to adverse, as drinking ethanol hinders the absorption of thiamine (B1), riboflavin (B2), niacin (B3), biotin (B7) and folic acid (B9). In addition, one of the previous studies highlights that high intakes of beer and other alcoholic beverages result in a net B deficiency and a health risk of these deficits [3].

Vitamin B12 cannot be present in excess of plant products, which makes B12 deficiency a valid vegetarian problem. Plant-based food producers often report B12 materials, giving rise to doubts as to which sources supply B12. Confusion is caused by the inability to quantify B12 directly with the US Normal Pharmacoepia (USP) process. The bacterial reaction to food is measured instead. Chemical B12 vitamin derivatives are useful for bacteria present in plant foods, but cannot be used in the human body. Similarly, B12 levels may also be over-reported in other food categories as a result [4].

The use of dietary supplements is a common way of improving the consumption of vitamin B. B vitamins are usually used in energy drinks and many are advertised with high levels of B vitamins boasting that they can 'go through the day and do not feel nervous or anxious.' Some nutritionists critically argue, for example, that while B vitamins ‘help to transfer energy to food,’ most Americans have the necessary supplements to supplement B vitamins [5].

Excess B vitamins are usually easily excreted because they are water soluble, although absorption, use and metabolism may vary from person to person. Elderly people and athletes will need to add B12 and other B vitamins to their diets due to absorption difficulties and improved energy output requirements. B vitamins, in particular B12, can also be administered by injection to reverse deficits in cases of extreme deficiency. It is also recommended that thiamine be replaced for type 1 and type 2 diabetes, depending on the elevated prevalence of low plasma thiamine levels and increased thiamine clearance. In addition, early embryo development deficiencies in vitamin B9 (folic acid) have been associated with neural tube defects. Women's pregnancy is therefore generally recommended to increase the consumption and/or replacement of folic acid in their normal diet [8-10].
Table-2: Vitamin B complex structure, function and sources

<table>
<thead>
<tr>
<th>Vitamin</th>
<th>Structure</th>
<th>Function</th>
<th>Sources</th>
</tr>
</thead>
</table>
| B1 (Thiamine) | ![Structure](image1) | - Release of energy from carbohydrates  
- Involved in central dogma  
- Converts pyruvate to acetyl CoA | Beef, liver, dried milk, nuts, oats, oranges, eggs and legumes |
| B2 (Riboflavin) | ![Structure](image2) | - Release of energy in ETC and CAC  
- Beta oxidation of fatty acids | Milk, bread, fortified cereals, almond, asparagus and meat |
| B3 (Niacin) | ![Structure](image3) | NAD and NADP are two co-enzyme forms:  
- Both are involved in energy transfer reactions during glucose, fats and alcohol metabolism.  
- NAD is involved in CAC  
- NADP is involved in lipid and nucleic acid formation. | Beans, milk, meat and eggs |
| B5 (Pentothenic acid) | ![Structure](image4) | Oxidation of fatty acids and carbohydrates synthesis of amino acids, fatty acids, ketone bodies, cholesterol, phospholipids, steroid hormones, neurotransmitters and antibodies | Dried mushroom, liver, dried egg yolks, sunflower seeds |
| B6 (Pyridoxine, pyridoxal, pyridoxamine) | ![Structure](image5) | Act as cofactor | Poultry, fish potatoes, chickpeas and banana |
| B7 (Biotin) | ![Structure](image6) | Act as co-enzyme for carboxylases | Soybean, butter, sunflower seeds, lentils, peanut, walnuts and eggs |
| B9 (Folic acid) | ![Structure](image7) | - Synthesis of purines and pyrimidine  
- Aid in erythropoiesis | Pasta, fruits, vegetables, sunflower seed, soy seeds, fortified cereals |
| B12 (Cobalams) | ![Structure](image8) | - Function as co-enzyme  
- Involved in metabolism of carbohydrates, lipids and protein | Fish, meat, poultry, eggs, milk, and milk products |
Vitamin C

The first vitamin C was discovered in 1912, isolated in 1928, and first chemically developed in 1933. The safest and most effective medicines needed in the health care system are on the World Health Organization list of essential medicines. Vitamin C is used as a low-cost prescription drug. The 1937 Nobel Prize in Physics and Medicine and Chemistry was awarded to Albert Szent-Györgyi and Walter Norman Haworth for his research. Citrus fruits, kiwi-fruits, guava, broccoli, sprouts, bell peppers and strawberries are foods containing vitamin C. Long storage or cooking of food can reduce vitamin C levels [11, 12].

Functions

Vitamin C is needed for tissue growth and repair in all areas of the body. It is used as an essential protein for the development, repair and maintenance of cartilage, bones and teeth and assists in the absorption of iron. It provides flesh, tendons, ligaments and blood vessels, heals wounds and shapes skin tissues. Vitamin C is one of many antioxidants. Antioxidants are nutrients that prevent damage to some free radicals. Free radicals are produced when your body breaks down food or when you are exposed to cigarette smoke or radiation. Free radicals develop over time, and the ageing process is a key factor. Free radicals can be critical in conditions such as cancer, heart disease and arthritis. Vitamin C has been a common cold treatment in the history for several years. Data indicate that most people are not at risk from the common cold of vitamin C supplements or vitamin C-rich foods. However, people who take vitamin C supplements on a daily basis may experience milder effects or marginally shorter colds. It does not seem necessary to take a vitamin C supplement at the start of the cold [13, 14].

Sources

Both fruits and vegetables have vitamin C content. Cantaloupe, citrus fruits and juices such as orange and grapefruit, kiwi fruit, strawberry, papaya, pineapple, beer, raspberries and watermelon provide the highest amount of vitamin C [15, 16]. Veggies with the highest levels of vitamin C include: broccoli, sprouts and cauliflower in Brussels, green and red peppers, lettuce, spinach, turnip greens and other leafy greens, tomatoes and tomato juice, squash in winter. Few cereals and other foods and drinks include fortified vitamin C. Fortified indicates that the product has been supplemented with vitamins or mineral [17-20].

Cooking or preserving foods rich in vitamin C will reduce the amount of vitamin C for a long time. Vitamin C-rich foods can reduce the loss of cooking by microwaving and steaming. Uncooked or processed fruit and vegetables are the safest food sources for vitamin C. Light sensitivity can also reduce vitamin C.

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Table-3: Indication of vitamin B complex deficiency, toxicity and absorption

<table>
<thead>
<tr>
<th>Vitamin</th>
<th>Deficiency</th>
<th>Toxicity</th>
<th>Absorption</th>
</tr>
</thead>
<tbody>
<tr>
<td>B1 (Thiamine)</td>
<td>• Beriberi&lt;br&gt; • Wernicke encephalopathy&lt;br&gt; • Edema&lt;br&gt; • Dementia</td>
<td>Not reported</td>
<td>Absorbed through jejunum and intestinal mucosal cells through active and passive transport</td>
</tr>
<tr>
<td>B2 (Riboflavin)</td>
<td>• Ariboflavinosis&lt;br&gt; • Cheilosis&lt;br&gt; • Glossitis&lt;br&gt; • Seborrheic dermatitis&lt;br&gt; • Pharyngitis</td>
<td>Rare.&lt;br&gt; Damage liver.</td>
<td>Absorbed in proximal small intestine</td>
</tr>
<tr>
<td>B3 (Niacin)</td>
<td>• Pellagra</td>
<td>Liver damage.&lt;br&gt; Glucose Intolerance.&lt;br&gt; Hyperuricemia.&lt;br&gt; Macular edema&lt;br&gt; Macular cysts</td>
<td>Primarily absorbed in small intestine. Some quantity is absorbed in stomach.</td>
</tr>
<tr>
<td>B5 (Pentothenic acid)</td>
<td>• Acne&lt;br&gt; • Paresthesia</td>
<td>Not reported</td>
<td>Absorbed through intestinal cells via a saturable, sodium-dependent active transport system.</td>
</tr>
<tr>
<td>B6 (Pyridoxine, pyridoxal, pyridoxamine)</td>
<td>• Seborrheic dermatitis&lt;br&gt; • Epilepsy&lt;br&gt; • Pink eyes</td>
<td>Ataxia, hearburn, nausea, skin lesions, photosensitivity and numbness</td>
<td>Absorbed in jejunum through passive diffusion</td>
</tr>
<tr>
<td>B7 (Biotin)</td>
<td>Growth and neurological disorders in infants</td>
<td>Eosinophilic pleuropericardial effusion</td>
<td>Absorbed through small intestine</td>
</tr>
<tr>
<td>B9 (Folic acid)</td>
<td>Macrocytic anemia</td>
<td>Sleep disturbances, mental confusion, skin reactions, loss of appetite, nausea, seizures and gastrointestinal defects</td>
<td>Absorbed primarily in the duodenum and jejunum within the acid microenvironment at the cell surface</td>
</tr>
<tr>
<td>B12 (Cobalamin)</td>
<td>• Macrocytic anemia&lt;br&gt; • Pernicious anemia</td>
<td>Acne and rosacea</td>
<td>Absorbed through ileum</td>
</tr>
</tbody>
</table>

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levels. Choose an orange juice preserved in a box instead of a clear bottle [21].

Deficiency

Vitamin C deficiency is referred to as Scurvy. It can cause anaemia, fatigue and vomiting, sudden haemorrhage, pain in the arms and legs, swelling in the body, often gum ulceration and loss of teeth [22].

Toxicity

Vitamin C is a water-soluble vitamin that does not consume dietary excesses and quickly excretes from the blood into the urine and therefore has a relatively low acute toxicity. More than two or three gm of indigestion will occur, especially if the stomach is empty [23]. However, vitamin C can minimise this effect in the form of sodium ascorbate and calcium ascorbate. Other symptoms reported at large doses include nausea, abdominal cramps and diarrhoea. The osmotic influence of vitamin C flowing through the intestine is responsible for these effects. Theoretically, high vitamin C intake can contribute to a lack of iron absorption [24]. This issue has never been recorded in a review of supplementary tests for healthy subjects, but the likelihood that people with hereditary hemochromatosis may suffer adversely has not been demonstrated [25-28].

Absorption

Active transport and simple diffusion absorbs ascorbic acid throughout the body. The two protein carriers necessary for active absorption are sodium-dependent active transport -Sodium Ascorbate Co-Transporters (SVCTs) and Hexose (GLUTs). The reduced form of ascorbate is transported through the plasma membrane by SVCT1 and SVCT2. Glucose transporters are GLUT1 and GLUT3 and pass vitamin C dehydroascorbic acid (DHA) only. Although dehydroascorbic acid is more absorbed than ascorbate in normal plasma and tissues, dehydroascorbic acid is rapidly converted into ascorbate [29, 30].

CONCLUSION

There are different functions of water soluble vitamins. Excretion of some water soluble vitamins and ascorbic acid may be caused by urine. In individuals, vitamin C is reabsorbed by the kidneys instead of excreted during periods of reduced dietary intake. Re-absorption reduces and excess volumes can easily enter the urine only when plasma concentrations are 1.4 mg / dL or higher. This recovery will prolong the onset of the shortcoming. Humans are better at turning DHA back into ascorbate than guinea pigs and thus lowering the risk of vitamin C deficiency and other water soluble viatmins.

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