**VITAMINS**

Vitamins are small organic molecules demanded by the body in minute amounts (in micrograms to milligram quantities per day) that are essential for the body to carry out metabolic functions. With the chemical nature of vitamins initially unknown, letter designation such as A, B, C was applied for their nomenclature.

Today, vitamins are found to have different chemical nature, being aldehydes, alcohols, organic acids, their derivatives and even of nucleotide derivatives, such as Vitamin B1. Vitamins include 14 essential compounds that cannot be synthesized or produced in sufficient quantities by the body and hence requires to be supplied in diet.

There are two major classification of vitamins:

1. Fat soluble vitamins
   1. Vitamin A (Retinol)
   2. Vitamin D (Cholecalciferol)
   3. Vitamin E (Tocopherol)
   4. Vitamin K
2. Water soluble vitamins
   1. Vitamin B1 (Thiamin)
   2. Vitamin B2 (Riboflavin)
   3. Vitamin B3 (Niacin)
   4. Vitamin B5 (Pantothenic Acid)
   5. Vitamin B6 (Pyridoxine)
   6. Vitamin B7 (Biotin)
   7. Vitamin B9 (Folate)
   8. Vitamin B12 (Cobalamin)
   9. Vitamin C (Ascorbic Acid)

Fat Soluble vitamins are rich in aliphatic and aromatic side chains, with less **hydroxyl** groups for which they are primarily non-polar and soluble only in lipids and fats and usually requires to be transported in the body by means of **chylomicrons**.

Unlike fat soluble vitamins, water soluble vitamins have more hydroxyl and nitrogen in their structure, enabling them to form more hydrogen bonds and making them polar in nature. Therefore, water soluble vitamins dissolve in water and are usually excreted via urine from the body when in excess, except for Vitamin B12 due its complex structure. However, the fat-soluble vitamins, when in excess, are usually stored in fatty tissues and the liver and thus can cause harm if taken in excess. Both fat and water-soluble vitamins have significant functions in managing vital reactions and maintaining the metabolism of the body by acting as precursors for coenzymes, antioxidants and hormones.

Depending on the structures, the solubility of the vitamins can be observed to significantly effect absorption, storage, transportation and excretion of the vitamins, which are discussed in the section below:

**Structural Discussion**

**Vitamin A:**

Two main preforms of vitamin A are usually found in human diet, namely, **retinol** and **provitamin** A, beta carotenoid (Office). Significant sources of such preforms of Vitamin A are carrots, tomatoes, peaches, sweet potatoes, beef and cod liver. It’s a fat-soluble vitamin, which consists of a 6 membered ring attached with an 11-carbon side chain. Vitamin A dominantly consists of the three active biological molecules- Retinol, Retinal and Retinoic acid that are derived from Beta carotene (Fig:1.0).

NADH

Beta Carotene

Beta-carotene dioxygenase

Figure:1.0: Formation of Retinal, Retinol and Retinoic Acid from Beta-Carotene by Beta-carotene dioxygenase.

The synthesis of vitamin A takes place in the intestine, where B-carotene dioxygenase acts on beta carotene in the presence of NADPH to reduce retinal to retinol. The retinol is further esterified with palmitic acid in chylomicrons along with dietary lipid for absorption.

Figure 1.1: Form of retinal present in retina of eyes.

Functions of Vitamin A:

1. Promotes good eye sight by producing the pigment, rhodopsin, in eye by means of Wald’s visual cycle.
2. Retinoic acid acts a gene regulator, controlling the biosynthesis of cholesterol, membrane glycoproteins and glycosaminoglycans.
3. Controls the rate of gluconeogenesis in the liver by stimulating transcription of phosphor-enol pyruvate carboxykinase enzyme.
4. Involved in cellular differentiation of epithelial cells, spermatogenesis and in the growth and development of neoplasm.
5. Reduces risk of cardiovascular diseases, due to antioxidant traits of Beta carotene.
6. Helps to maintain healthy teeth, skeletal and soft tissues (Vitamin A).
7. Known to help with immune function (Vitamin A).

The recommended daily average (RDA) intake of vitamin A for an adult man and women is about 900 mcg and 700mcg respectively. It is important to take note on not ingesting an excess of vitamin A since it could lead to toxicity resulting hypervitaminosis A, which can lead to bone pain, vision change and even death, with birth defects for pregnant women. However, a deficiency of vitamin A leads to night blindness, xerophthalmia, skin diseases, nerve lesions, impaired lipid absorption and chylomicron formations, certain enzymatic defects etc. Therefore, it is vital to ensure an optimal intake of vitamin A daily.

Vitamin A as a therapeutic Supplement:

Since 1941, vitamin A has been introduced as a supplement that gained popularity as it was known to reduce mortality, measle complications as well as to treat acute promyelocytic leukemia (Naik).

Interestingly, even though Vitamin A in excess can result toxicity, no research yet has established toxicity due to high intake of beta carotene. Hence, it is rather suggested to take more beta carotene if needed rather than vitamin A rich foods or vitamin A supplements (Vitamin A, 2019).

**Vitamin D:**

Fatty fish such as tuna, salmon, dark green vegetables, soy, egg yolk, beef liver are rich in vitamin D. Sunlight has also been found to be a source of vitamin D for humans, since the UV light in sun rays, enables skin to make its own vitamin D. However, sunscreens can damage 95% of the skin’s ability to produce vitamin D, leading to deficiency. There are two main forms of vitamins- D3, known as cholecalciferol (the natural form obtained from animal source in diet and sun) and ergocalciferol (vitamin D2), which is synthesized in the laboratory (Fig 1.3).

Figure 1.3: Vitamin D2 and Vitamin D3

The side chains are different in the both structures but they function similarly to hormonally activate dihydroxy forms.

NADPH, O2

Cytochrome P450

1, Alpha-hydroxylase

NADPH

25-hydroxylase Cytochrome P450

Figure 1.4: Biosynthesis/activation of Vitamin D.

1:25 dihydroxycholecalciferol is the active form of vitamin D, processed in the kidneys and the biosynthesis of the compounds depends on the plasma concentration of calcium ion, parathyroid hormones, insulin, estrogen and plasma phosphate concentration as they act as inhibitors for 1, Alpha-hydroxylase enzyme. However, the product 1, 25 dihydroxycholecalciferol itself if a potent inhibitor of the enzyme, 1, Alpha-hydroxylase, itself regulating the concentration.

Functions of Vitamin D:

1. Vitamin D plays significant role in calcium homeostasis (carried by 1, 25 dihydroxycholecalciferol).
2. The activated form of vitamin D acts as a hormone, regulating cell growth and differentiation such as for immunoregulatory cells, epidermal cells and even for malignant tumor cells.
3. Responsible for proper calcification of bone, it helps in the mobilization of calcium and phosphate from the bone.
4. Regulates insulin secretion, parathyroid and thyroid hormones.
5. Associated with muscle function and posture stability (Rejnmark, 2011).

Deficiency in vitamin D can result rickets in children and osteomalacia in adults (prolonged effect) and Kyphosis (swollen abdomen condition). Moreover, according to a research, deficiency of vitamin D is also linked to the development of liver diseases, kidney failure, breast and colon cancers (Edlich et.al, 2009). On the other hand, high doses/intake of vitamin D can be fatal (vitamin D, where ‘D’ stands for Death). Excess intake of vitamin D results hypercalcemia, where many tissues apart from bones can get calcified and can even lead towards death. Therefore, although vital for the body, Vitamin D is required to be ingested by 400-800IU amount per day. As for therapeutic purposes, 16-65 pg/ml of 1, 25 dihydroxy vitamin D and 14-60pg/ml of 25-hydroxy vitamin D is suggested.

**Vitamin E:**

Vitamin E are antioxidants, present in palm, soya, olive, coconut and safflower oils. It’s the collective name for eight fat soluble vitamins.



Figure 1.5: Chemical structure of Vitamin E.

Vitamin E are stored in adipose tissues in the body. They are absorbed via lipid by being incorporated in chylomicrons and taken to the liver, where it’s distributed to targeted regions where needed.

Function:

1. Acts as natural antioxidants.
2. Prevents peroxidation of polyunsaturated fatty acids.
3. Protection of Erythrocyte membrane from oxidants.
4. Protects against coronary heart diseases.

The RDA for vitamin E is 10mg and 8 mg for men and women respectively. With no known toxic effects and a rare vitamin deficiency to suffer from, given that it’s a fat-soluble vitamin, condition resulting malabsorption of fat can lead to vitamin E deficiency, causing neuropathy in children, premature and low birth weight, as well as hemolytic anemia.

**Vitamin K:**

Egg yolk, tomatoes, cheese, meat, cabbage, cauliflower, kale, spinach and any notable green vegetables are rich in vitamin K.

There are usually two natural forms of vitamin K, namely vitamin K1, and Vitamin K2.

Vitamin K1 is derived from plants, known as phylloquinone and Vitamin K2, produced by microorganisms are menaquinones. The third form, vitamin K3, menadione is synthetic, made by the alkylation of vitamin K2.

Absorbed only in the presence of bile salts and transported via chylomicrons, vitamin K is stored in the liver. An exception is Vitamin K3, which is synthetic and water soluble and thus can be directly taken to the liver via the hepatic portal vein.







Figure 1.6: Vitamin K1, K2, K3 (from top to bottom)

Function:

1. Plays an active role to synthesis various blood clotting factors.
2. Performs post transcriptional modifications on glutamate residues of inactive proteins, functioning as carboxylase co-factor.
3. Acts as Calcium ion chelators, interacting with prothrombin and help in wound healing by initiating blood clot mechanism.
4. Required for the carboxylation of glutamic acid residues of osteocalcin (calcium binding protein in bone).
5. Plays an active role in Vitamin K cycle in the liver to regenerate active forms of vitamin K.
6. Counteracts poisonous effect of dicumarol type drugs

RDA for vitamin K for adults is about 70-140 microgram/day, provided that the absorption efficiency may vary from 10-70%.

Given that vitamin K can be found in almost all common foods as well as synthesized by the gut microbiome, vitamin K deficiency is relatively rare. Exception are for people who suffer from fat malabsorption, has liver diseases, people on antibiotic therapy that can affect the intestinal flora or in newborn infants. Vitamin K deficiency can lead to severe hemorrhage, resulting reduced prothrombin and vital blood clotting factors. For such people, the synthetic vitamin K3 (which is water soluble) is usually suggested. However, the synthetic vitamin K, menadione, was reported to result hemolytic anemia and low birth weights in rats, due to increased erythrocytes.

**Vitamin B1:**

Found in peas, whole grains, nuts and meats, Vitamin B1 or thiamine, cannot be synthesized by the body and therefore needs to be taken exogenously in the diet. It is absorbed readily in the small intestine and its phosphorylation (activation) takes place in the jejunal mucosa. Vitamin B1 is heat labile and hence can be lost while cooking. It plays a significant role in the digestion of carbohydrates mostly serving as cofactors for oxiductases enzymes.

Vitamin B1 is a colorless crystalline substance that readily dissolves in water and slightly soluble in ethyl alcohol (Rasaq).

Methylene Bridge



Thiazole Ring

Pyrimidine Ring

Figure 1.7: Structure of Thiamine

Thiamine consists of a pyrimidine ring structure bonded to a thiazole ring via a methylene bridge (Fig. 1.7). Hence, synthesis of thiamine requires an independent formation of the two ring structures and their subsequent condensation (Iwashima, 1989; Leder, 1975).

When phosphorylated, Thiamine forms an activated coenzyme, Thiamine Pyrophosphate (TPP), upon the addition of pyrophosphate from ATP.

The active coenzyme form of Thiamine serves several functions:

1. TPP is the coenzyme for all decarboxylation of alpha ketos. For example, The decarboxylation of alpha-oxoglutaric acid in the citric acid cycle (Rasaq; Schnepp, 2002)
2. The conversion of alanine to pyruvic acid then to acetyl coenzyme A (Schnepp, 2002).
3. Essential for neural function since the TPP acts as a phosphate donor for phosphorylation of nerve membrane transporter of Na+.
4. Necessary for ATP, [ribose](https://www.sciencedirect.com/topics/agricultural-and-biological-sciences/ribose), NAD, and DNA production (Vitamin B1).

The recommended daily average requirement of thiamin is approximately 1.2-1.4 mg in men and 1mg in women (more for pregnant and lactating women). For infants, the suggested daily intake is between 0.2-0.5mg. It is vital that the diet includes proper amounts of vitamin B1 to avoid deficiency symptoms such as lactic acidosis, Wernicke’s encephalopathy with Korsakoff’s psychosis, which is associated with alcohol and drug abuse, with extended cases of heart failure and edema.

**Vitamin B2:**

Vitamin B2 or riboflavin, can be obtained from egg, dark meat, kidneys, liver, milk, green vegetables. Consisting an isoalloxazine ring and a ribitol side chain, it’ a yellow compound that is widely used as food coloring.

Riboflavin has two active forms Flavinmononucleotide (FMN) and Flavin adenine dinucleotide (FAD) (Fig 1.8). These flavocoenzymes derived from riboflavin are perhaps the most chemically versatile cofactors (Fischer et.al, 2008).

Amongst the many functions of Riboflavin, some significant functions of the vitamin are:

1. Helps in the formation of ATP from carbohydrates.
2. Acts as the precursor of the activated form of vitamin B2 coenzymes, FMN and FAD, which are needed for several oxidoreduction pathway reactions such as deamination of proteins, citric acid cycle, purine degradation, fatty acid oxidation etc. The FMN and FAD are usually the electron carriers in the reactions.
3. Aids to metabolize iron, pyridoxine and folate.
4. Ensures proper fetal development, healthy liver function, protein breakdown, maintaining healthy mucous membranes.
5. Converts Vitamin B6 to its coenzyme.
6. Helps to convert tryptophan to niacin.

**Synthesis of vitamin B2:**

The biosynethesis of Vitamin B2 initiates with GTP cyclohydrase II, which then follows a series of reactions to finally provide riboflavin that is then converted to FMN and FAD.

ATP

ATP

ADP

PP



Figure 1.8: Formation of FMN to FAD from Riboflavin.

Having no relatively known toxic effects if ingested in excess (mainly because it’s a water-soluble vitamin having the ability to be excreted), for adults, the RDA of vitamin B2 is about 1.3-1.7 mg. The daily requirement is subjected to increase during growth, pregnancy, wound healing, lactation since the required amount of Vitamin B2 is related to the amount of protein used/needed by the body.

Although, B2 deficiency rarely occurs due to recycling property of FMN and FAD and the availability of riboflavin across various foods, certain conditions such as avitaminosis, hyperbilirubinemia, anorexia, chronic alcoholism may lead towards vitamin B2 deficiency by inducing microsomal oxidation of the vitamin. Such deficiency can lead towards inflammation of mouth and tongue, seborrheic dermatitis, vascularization of cornea, hinderance in the conversion of vitamin B6 to its coenzyme and the conversion of tryptophan to niacin.

**Vitamin B3:**

Niacin, the third water soluble vitamin to be discovered is termed as vitamin B3. Good sources of vitamin B3 can be found in mushrooms, liver, nuts, green vegetables, eggs, yeasts, poultry, meat, pumpkins.

Named from nicotine acid and nicotinamide, niacin is a derivative of pyridine, chemically termed as pyridine-3-carboxylic acid (C6H5NO2) (Fig:1.9a, 1.9b).

Along with vitamin D, vitamin B3 or Niacin, is the only other known vitamin that can be synthesized by the body. It’s the liver which synthesizes niacin from the essential amino acid tryptophan in diet, which undergoes a series of reaction to give Niacin (Libretexts, 2019). The figure below demonstrates a simplistic reaction pathway for the process (Fig: 1.9b)



Figure 1.9a: Chemical structure of Nicotinic Acid.

NADH

NADPH

Vitamin B6

Figure 1.9b: Synthesis of Niacin from the Amino acid Tryptophan

Function of Niacin:

1. Used in the formation of NAD+ and NADP+ which are active coenzymes of dehydrogenases for various oxidation reduction reactions, primarily in citric acid cycle and glycolysis.
2. NAD is known to take part in DNA repair.
3. Plays role in cholesterol and fatty acid synthesis and pentose phosphate pathways.

High doses of Nicotinic acid are known to reduce risks of cardiovascular diseases, hence used as an additional supplement to lipid lowering medications (Libretexts, 2019). However, over dosage/high intake of niacin may lead to liver damage and vasodilation resulting adverse effects. Hence, the RDA for Vitamin B3 is around 15-20mg, where tryptophan alone provides 10% of the total daily requirement. Deficiency of Niacin can lead to pellagry, a disease that can result dermatitis, diarrhea, dementia and even death. However, a deficiency of vitamin B6 can also lead to niacin deficiency due to vitamin B6’s conezymatic activity in niacin synthesis pathway.

**Vitamin B5:**

Liver, eggs, wheat germs are significant sources of Vitamin B5. This vitamin can be synthesized upon reacting pantoic acid and beta alanine with the removal of a water molecule.

Figure 2.0: Synthesis of Pantothenic Acid

The active forms of pantothenic acid are Coenzyme-A and Acyl carrier protein (ACP). Pantothenic acid in the form of CoA, is required for acylation and acetylation, which, for example, are involved in signal transduction and enzyme activation and deactivation, respectively. Moreover, along with CoA, ACP is also vital for reactions concerning cholesterol synthesis. Since pantothenic acid participates in a wide array of key biological roles, it is essential to all forms of life. As such, deficiencies in pantothenic acid may have numerous wide-ranging effects (Libretexts, 2019). To date, no confirmed RDA for vitamin B5 has been established due to rarity of its deficiency. Only malnourished people who suffered from other vitamin deficiencies was vitamin B5 deficient. Although rats were observed to have grey hair, cornea vascularization the area still requires further research.

**Vitamin B6:**

Pyridoxine is an essential water-soluble vitamin, found in chick peas, potatoes, avocadoes, brown rice, poultry fish, eggs, milk, apples, meat and other plant and animal products.

Vitamin B6 comprises of pyridoxine, pyridoxal and pyridoxamine and upon the phosphorylation of the three forms of the pyridine derivative by a cytosolic FMN-dependent oxidase, the active form- Pyridoxal Phosphate (PLP) is generated (Fig: 2.1). In our body, brain, liver and muscle has the highest vitamin B6 composition (80%) as such organs are associated with stores of pyridoxin and the enzyme glycogen phosphorylase.



Figure 2.1: Chemical Structure of Pyridoxal Phosphate, activated form of Vitamin B6.

One of the main biological function of the PLP, the activated form of vitamin B6 is its role as coenzyme. for many reactions, especially for amino acid metabolism. Additional vital functions include:

1. Amino transferase reactions (converting aspartate transaminase to alanine transaminase.
2. Roles in neurotransmission as amino acid decarboxylases.
3. Deamination reactions of serine, tryptophan, cysteine.
4. Conversion of tryptophan to serotonin and vitamin B3.
5. Production of heme via aminolaevulinic acid synthetase.
6. Steroid hormone action, terminating hormonal actions by removal of the receptor complex from DNA.

Vitamin B6 is known to be issued for the treatment of seizures, down’s syndrome and premenstrual tension syndrome. Deficiency of vitamin B6 therefore could cause microcytic hypochromic anemia, peripheral neuropathy and hormonal imbalances leading towards breast and prostate cancers. Hence, the RDA for vitamin B6 is 1.6mg to 2.0mg that is subjected to increase during pregnancy and lactation period. However, high intake was observed to result peripheral neuropathy within 1-3 years.

**Vitamin B7/H:**

Egg yolk, liver, kidneys vegetables are some of the important sources of Biotin or vitamin H. It can also be synthesized by the gut microbiome present in the small intestine. Biocytin that is found in nature acts as a precursor of Biotin. Biotin consists of a fused imidazole & thiophene ring with a valeric acid side chain (consisting amino group of lysine residue and carboxylase bonded together) (Fig: 2.2). Readily absorbed by the liver and muscle tissues, the significant biological roles of biotin are:

1. Required in the conversion of acetyl CoA to malonyl CoA via acetyl CoA carboxylase.
2. Helps in fatty acid synthesis.
3. Helps in the conversion of pyruvate to oxaloacetate.
4. Catabolizes branched chain amino acids
5. Converts propionate to succinate.
6. Helps to maintain proper hair, cell and skin.



Figure 2.2: Structure of Biotin

There is no particular RDA set for biotin since it is synthesized by the intestinal flora. Deficiency of biotin causing nausea, depression, hair loss, is therefore rare and can occur if diet consists of high antibiotic intake (effecting the gut microbiome), ingestion of uncooked egg (that consists avidin which reacts with imidazole of biotin).

**Vitamin B9/Folic Acid:**

A pteridine ring and a para-aminobenzoic acid residue (PABA), consisting variable glutamyl units joined via amide linkages, together forms folic acid. Leafy vegetables, legumes, asparagus, beets, broccoli, citrus fruits, rice are some significant sources of folic acid.

Folic acid requires to be activated to Tetrahydrofolate (THF), with the help of vitamin C, to carry out certain biological functions. Firstly, the folate is reduced and methylated and then carried in the plasma once bound to particular proteins. The activation of Folic acid to THF is shown below:



NADPH + H+

=

Folate Reductase + Vitamin C



NADP+

Folate Reductase + Vitamin C

NADPH + H+

=

NADP+



Figure 2.3: Formation/Activation of THF from folic acid.

Functions of THF:

1. A carrier of one carbon fragments by accepting carbon units from degradation sites through N5, N10 and donating to synthesis reactions such as in the conversion of serine to glycine, synthesis of thymidylate, methionine, purine, homocysteine, catabolism of histidine.
2. Prevents changes in the DNA that may lead to cancer (Entrigner, 2019; Felmer, 2011)
3. Helps to prevent anemia (Entrigner, 2019; Folic).
4. Associated with growth and development.
5. Aids vitamin B12 during methyl group transfer.

The RDA of folic acid is around 200mg, which is likely to increase during pregnancy and lactation. Folic acid is a vital requirement for the body and deficiency can lead to birth defects in pregnant women, neural tube defects, sensory loss, megaloblastic anemia (since DNA synthesis is impaired) and excretion of formiminoglutamic acid (FIGLU) through urine. Folic acid can be taken as a dietary supplement, however, people with kidney diseases, hemolytic anemia is advised to have special dosage adjustments under medical supervision due to certain side effects of the supplement such as shortness of breath, skin irritability, dizziness etc. Hence, it is always advisable to ensure folic acid is obtained from the nutrition in food through a balanced diet.

**Vitamin B12:**

Vitamin B12, known as cobalamin is usually of animal origin, present in eggs, milks, fishes, meat, sardines, with small amounts made available from the gut microbiome.

Having a coring ring, Cobalamin is a complex, consisting a cobalt atom in a co-ordinate bond with nitrogen of pyrol groups, dimethylbenzimidiazole nulcetotide (Fig: 2.4).

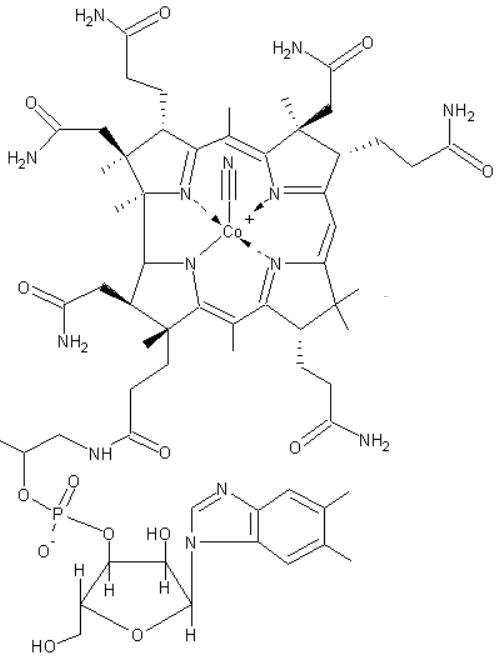


Figure 2.4: Structure of Cobalamin.

Commercially, cyanocobalamin acts as a vitamin B12 supplement.

The active forms of Vitamin B12 are methycobalamin and deoxyadenosylcobalamin.

Given that cobalamin is a complex compound, for the absorption of vitamin B12, it first requires to be accompanied by salivary proteins called haptocorin to the stomach, where it is broken down when bound to intrinsic factors that are secreted by the patrialc cells of the stomach. From the stomach, v12-IF complex (broken form of Vitamin B12) is then transported via hepatic portal vein by the hepatocytes and transported in plasma by transcobalamin I (haptocorrin) and transcobalamin II, before being stored in liver, bone marrow and tissues in significant amounts. Hence, vitamin B12 deficiency is usually not evident.

Function:

1. Deoxyadenosylcobalamin (a coenzyme, an activated vitamin B12 form), coverts methylmalonic acid to succinic acid.
2. Maintains the metabolism of fatty acids and aliphatic amino acids.
3. Methylcobalamin converts homocysteine to methionine acting as a transferase, aiding in the metabolic process of folic acid and vitamin B12 itself.
4. Helps un neuronal metabolism, brain function.
5. Helps in the production of red blood cells (Felman, 2017).

The RDA for an adult is 400 micrograms, with higher requirement during pregnancy and lactation. High intake of vitamin B12 is not known to be toxic, however, a deficiency can result irreversible neurological disorders, megaloblastic anaemia and even folate deficiency (Felman, 2017). Moreover, conditions such as pernicious anaemia, altrophic gastritis can also lead to the malabsorption of vitamin B12, resulting a deficiency. Furthermore, the lack of Vitamin B12 may lead to the accumulation of Methylmalonyl CoA in blood and urine. Therefore, vegetarians and vegans are usually advised to ensure the intake of vitamin B12 in their diet, to avoid the consequences of such deficiency conditions.

**Vitamin C:**

Ascorbic acid, or Vitamin C, is rich in citrus fruits such as oranges, strawberries, potatoes, lemons, grapes, tomatoes, broccoli, cauliflower and spinach. Humans are unable to synthesize vitamin C and is therefore an important dietary requirement. Sensitive to oxygen, metal ions, alkali, heat, vitamin C is primarily a reducing agent and an antioxidant.

2H

Figure 2.5: Oxidation of Ascorbic Acid

Ascorbic acid is a derivative of hexose D-glucose. However, further oxidation can lead to the inactive form, 2, 3 Diketo-L-Gulonic Acid (Fig: 2.5).

Function:

1. Hydroxides proline and lysin during collagen biosynthesis.
2. Involved in the hydroxylation process of steroid hormones.
3. Plays role in hydroxylation reactions during adrenaline synthesis.
4. During carnitine synthesis, converts gamma-butyrobetaine to carnitine.
5. Helps during bile acid (cholic acid) formation.
6. Enhances enzymatic activity during tyrosine degradation.
7. Metabolizes folic acid to THF.
8. Facilitates the absorption of iron.
9. Prevents coronary heart disease by impairing LDL oxidation.
10. Its antioxidant property scavenges free radicals, preventing cancer by inhibiting nitrosamine formation.

Readily absorbed by the body from the stomach, the RDA of vitamin C is 60mg for adults and 70mg and 95 mg for pregnant and lactating women respectively. For people who have more fried substances, junk foods etc. in their diet, the RDA is usually higher to combat the free radicals produced.

Deficiency of vitamin c leads to scurvy, gum diseases, pain in joints, increased capillary fragility leading to easy bruising of skin, osteoporosis, anemia, delayed wound healing, weak immunity and cell regeneration capability.

Although vitamin C is known to be an antioxidant that boosts immunity and known to help with common cold, high intake of vitamin C cannot be absorbed from the intestine causing diarrhea and oxalate stones in kidneys.

**Conclusion:**

Apart from the discussed vitamins, other significant vitamins playing vital metabolic roles, maintaining brain, liver, heart, nerve, kidney and other crucial functions include Vitamin F, commonly known as Linolenic acid and Linoleic acid, followed by vitamin B11 (salicylic acid) and PABA, which is commonly used in sunscreens to block UV rays. Vitamins together with other enzymes and minerals carryout major activities within the body and such vitamins can be found extensively in nature, in both plants and animals, with some vitamins being made within the body (especially by human and animal’s gut microbiome).

Ingested from various plant and animal sources, vitamins are vital requirements for the body. However, vegans and vegetarians, people who abstain from the intake of any animal products (both meat, dairy and eggs for vegans and usually meat for vegetarians) (Eske, 2019), how do they get their daily nutritional requirement by sticking to plant dietary food origin is a matter of question. With certain restrictions for vegan and vegetarian diets, it is often of concern whether a vegan or vegetarian diet will lead towards any vitamin deficiency or not, particularly vitamin B12 deficiency. It is often advised for both vegans and vegetarians to ensure that their diet contains all the necessary requirements needed by the body.

Although vegans and vegetarians are advised to take supplements such as calcium, iron and certain vitamins like B12 and other B complexes, it has been observed that a vegan/vegetarian diet can be quite healthy and beneficial for the body (Jaacks et. al, 2016). Vegans and vegetarians are known to have the least risk of developing cardiovascular diseases as they receive their necessary dietary requirement (fats, carbohydrate, amino acids etc.) from legumes, fruits, vegetables, olive oil and nuts (Jaacks et. al, 2016; Eske, 2019). Hence, a vegan and vegetarian diet could rather be healthier, being beneficial for the body as well as to help maintain a sustainable environment.

**To Living a Long and Healthy Life:**

According to a recent research by Harvard Professor, David Sinclair, the possibility of reversing age is no myth. Lifestyle and choice of food have been observed to activated rejuvenating enzymes in the body that can potentially reverse age (Sinclair et.al, 2019Bilyue, 2019). The secrete to a healthy long life is in the food we eat, the amount we consume and physical labor. Taking our body in survival mode, facing occasional hunger, doing hard work and consuming in small amounts can actually help activate the certain enzymes in our body that are tied to longevity (Sinclair et.al, 2019; Bilyue, 2019). Hence, it is suggested and advisable that people consume healthy food, only when hungry, with occasional moments of undergoing hunger state (shifting the body into its evolutionary survival state), followed by frequent physical exercise and meditation. In short, no vitamins or food should be considered a medicine. They can be equally helpful and harmful depending on the amount consumed. Contradicting the ‘vitamin myth’ that was once believed, taking limited vitamins and following a lifestyle suggested by Dr. David Sinclair may therefore be the better option for a long and healthy life.

**Summary:**

Table 1.0 denotes the structure of the most common vitamins known today, with many more yet to be discovered:

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Vitamin | Chemical Name | Year Discovered | Food Source | Solubility | Consequence of Deficiency | Recommended Dietary Allowance | Upper Intake Level (UL/Day) | Overdose Disease |
| Vitamin A | Retinal, Retinol and four carotenoids including beta carotene | 1913 | Cod Liver Oil | Fat Soluble | Night blindness,  Nyctalopia, Xerophthalmia, Keratomalacia | 900ug | 3300ug | Hypervitaminosis A |
| Vitamin D | Cholecalciferol | 1920 | Cod Liver Oil | Fat Soluble | Rickets (in children) and osteomalacia (in adult) | 5.0-10 ug | 50ug | Hypervitaminosis D |
| Vitamin E | Tocopherol Forms-Alpha, Beta, Gamma, Delta, Tocotrienols | 1922 | Wheat germ oil, Unrefined vegetable oil | Fat Soluble | Occurrence of Lipid peroxidation, Hemolytic anemia in new born. | 15mg | 1000mg | Increased congestive heart failure seen in one large randomized study |
| Vitamin K | Phylloquinone, Menaquinones | 1931 | Leafy green vegetables | Fat Soluble | Increased clotting time, hemorrhage in children | 120ug | Not known | Increased Coagulation in warfarin |
| Vitamin B1 | Thiamine | 1910 | Rice Bran | Water Soluble | Causes Beriberi, Wernicke Korsakoff syndrome | 1.2 mg | Not Determined | Drowsiness or muscle relation when overdose |
| Vitamin B2 | Riboflavin | 1920 | Meat, Eggs | Water Soluble | Dermatitis Photophobia, Angular Stomatitis. | 1.3mg | Not known | Liver damage with doses >2g/day |
| Vitamin B3 | Niacin, Niacinamide | 1936 | Meat, Eggs, Grains | Water Soluble | Pellagra | 16.0mg | 35.0mg | Diarrhea, possibility of nausea and heartburn |
| Vitamin B5 | Panthoehic Acid | 1931 | Meat, Whole Grains, in many foods | Water Soluble | Burning Feet Syndrome | 5.0mg | Not known | Diarrhea; possibly nausea and heartburn |
| Vitamin B6 | Pyridoxine, Pyridoxamine, Pyridoxal | 1934 | Meat, Dairy Products | Water Soluble | Epileptiform convulsions, dermatitis, hypochromic anemia. | 1.3 – 1.7 mg | 100mg | Impairment of proprioception, nerve damage (doses > 100 mg/day) |
| Vitamin B7 | Biotin | 1931 | Meat, dairy Products, eggs | Water Soluble | Biotin Inhibition | 30.0ug | Not known | Not known |
| Vitamin B9 | Folic Acid, Folinic Acid | 1941 | Leafy vegetables | Water Soluble | Megaloblastic anemia | 400ug | 1000ug | May mask symptoms of vitamin B12 deficiency; other effects. |
| Vitamin B12 | Cobalamin, Cyanocobalamin, Hydroxocobalamin, Methylcobalamin, | 1926 | Liver, eggs, animal products | Water Soluble | Pernicious Anemia, Dementia | 2.4ug | Not known | Acne like rash (not conclusively established) |
| Vitamin C | Ascorbic Acid | 1920 | Citrus, Most Fresh fruits and vegetables | Water Soluble | Scurvy | 90.0mg | 2000mg | Vitamin C mega dosage |

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