Vitamins: Cornerstones of Health and Vitality in the Human Body

Shraddha Pandhari Thakur[1], Prof. Suraj P. Rajurkar[2]
[1]*B.Pharmacy Final Yr., Jagadambha Institute of Pharmacy & Research Kalamb Dist Yavatmal*
[1]*Assistant Professor, Jagadambha Institute of Pharmacy & Research Kalamb Dist Yavatmal*

Abstract: Vitamins are essential micronutrients that play critical roles in maintaining human health, growth, development, and overall well-being. Classified into fat-soluble (A, D, E, K) and water-soluble (B vitamins and C), these nutrients support various physiological processes, such as immune function, energy production, cell repair, and bone health. Since the body cannot synthesize sufficient quantities of these vitamins, they must be obtained from a balanced diet rich in plant and animal-based foods. Vitamin deficiencies can lead to significant health problems, including impaired immune response, developmental issues, and chronic diseases. Ensuring adequate intake of all thirteen essential vitamins is therefore crucial for preventing deficiency-related conditions and promoting long-term health

Keywords: vitamin, human health, Vitamins function, Vitamins dificiencies.

INTRODUCTION

Vitamins are a diverse set of molecules that are unable to be manufactured by the human body but are required for the bodys basic process to function properly.Like certain beneficial phytochemicals, many essential nutrients cannot be synthesized or are made in insufficient quantities by the body and, therefore, must be obtained through diet (75). Although a balanced diet typically provides the necessary vitamins, many people fail to meet minimum nutritional requirements, often requiring supplementation.

Vitamins are crucial for metabolism, growth, and proper bodily functions. While the body can synthesize vitamin D, all other vitamins must be supplied through food. Most vitamins consist of multiple related molecules, called vitamers. For example, vitamin E is composed of four tocopherols and four tocotrienols.Vitamins serve various biochemical functions. Vitamin A regulates the growth and differentiation of cells and tissues. The B vitamins act as cofactors or precursors to enzymes that play key roles in metabolic processes. Vitamins C and E function as antioxidants, protecting cells from damage caused by free radicals (76). Vitamin D has hormone-like properties, controlling mineral metabolism in bones and other organs.

Vitamins are classified into two types: fat-soluble and water-soluble. There are 13 essential vitamins for humans: four fat-soluble (A, D, E, and K) and nine water-soluble (vitamin C and the eight B vitamins). Water-soluble vitamins dissolve rapidly in water and are quickly excreted from the body, making urine output a good indicator of vitamin consumption (77). Because they cannot be stored easily, they need to be consumed more frequently. On the other hand, fat-soluble vitamins are absorbed with the help of lipids (fats) in the digestive system. However, an excess of fat-soluble vitamins, especially vitamins A and D, can accumulate in the body and lead to toxic conditions known as hypervitaminosis.

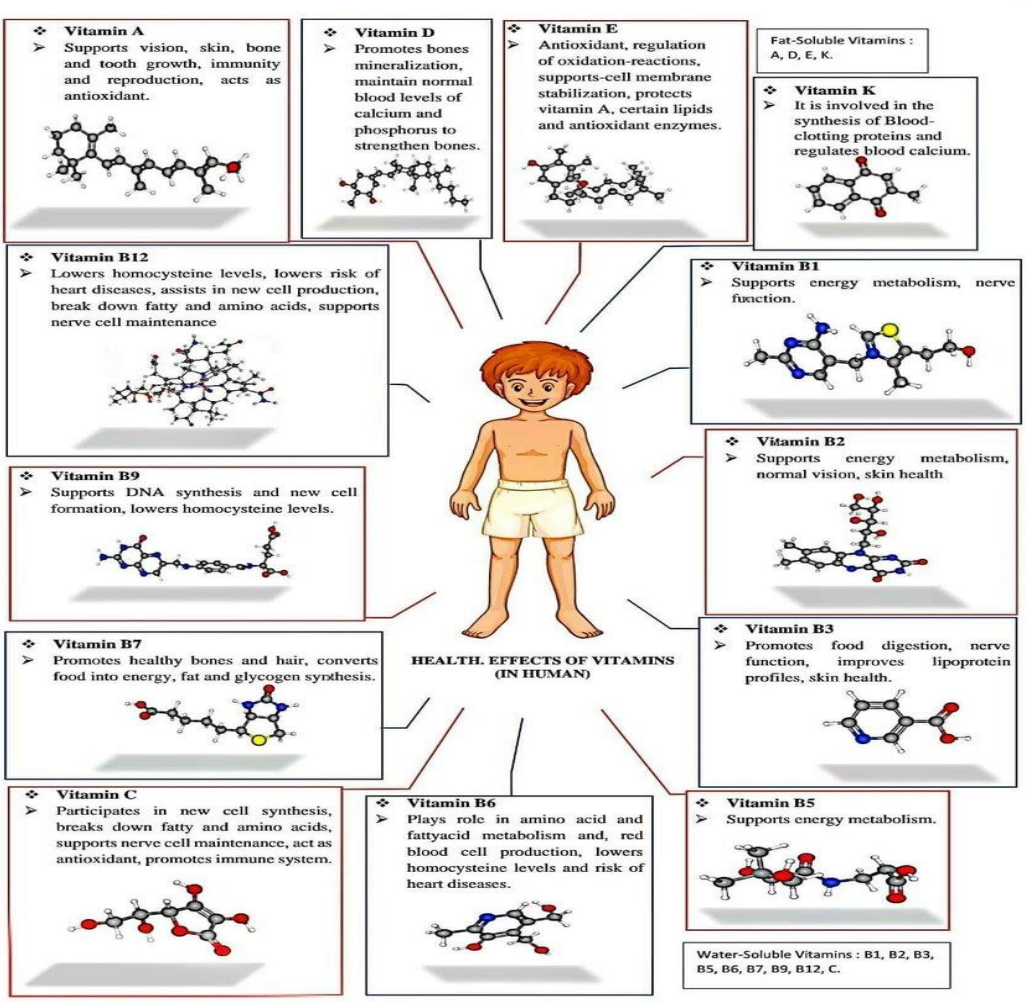


Fig.1 Vitamins and their role in human body (Structure- https://pubchem.ncbi.nlm.nih.gov)

Vitamin A

Vitamin A is one of the most complex vitamins in nature. It can be sourced from both plants and animals. The form obtained from animal sources is known as retinoids, while the form derived from plants is called provitamin A carotenoids.
Different forms of retinoids include retinol, retinal, retinoic acid, and retinyl esters. From plant sources, provitamin A carotenoids, such as α-carotene, β-carotene, and β-cryptoxanthin, are converted into preformed vitamin A retinoids during digestion in the human body .

Biological Importance:

Vitamin A is crucial for several functions, including maintaining vision, supporting the immune and inflammatory systems, facilitating cell growth and development, acting as an antioxidant, and promoting proper cellular communication .

Daily Requirementare:

The recommended daily intake of vitamin A is 900 micrograms for young males, 700 micrograms for females, and 300-400 micrograms for children(1).

Dietary Sources:

Food Stuff	RAEs µg	% of RDA
Liver (beef, pork, chicken, turkey, fish), cod liver oil	6500 µg	722 %
Carrot	835 µg	93 %
Broccoli leaf	800 µg	89 %
Sweet potato	709 µg	79 %
Butter	684 µg	76%
Kale	681 µg	76 %
Spinach	469 µg	52 %
Pumpkin	400 µg	41 %
Collard greens	333 µg	37 %
Cheddar cheese	265 µg	29 %
Cantaloupe melon	169 µg	19 %
Egg	140 µg	16 %
Apricot	96 µg	11 %
Papaya	55 µg	6 %
Mango	38 µg	4 %
Pea	38 µg	4 %
Broccoli	31 µg	3 %
Milk	28 µg	3%

These data are adapted from USDA database (http://www.nal.usda.gov/fnic/foodcomp/search/).
Abbreviations: RAEs, is retinol activity equivalences, % of RDA (**Recommended Daily Allowance**), is the average percentage of adult male per 100 grams of the food stuff.

Table 1. Dietary sources of vitamin A, retinol activity equivalences and percentage of recommended daily allowance

Vitamin A function:

Vitamin A performs multiple functions in the body due to its various biologically active forms. While retinol is the most abundant form, all-trans-retinoic acid (ATRA) is the primary active form of vitamin A(79,80,81,82,83,84). Other metabolites, such as 9-cis-retinoic acid and 13-cis-retinol, also have biological activity, though to a lesser degree. Each form of vitamin A has specific roles in different tissues and processes, yet they share common properties(85). Retinol functions as a cofactor in several enzymatic processes, 11-cis-retinal plays a key role in vision, and ATRA regulates gene expression by binding to nuclear receptors.

A summary of the wide range of physiological processes in which retinoids are involved is provided in Figure 2:

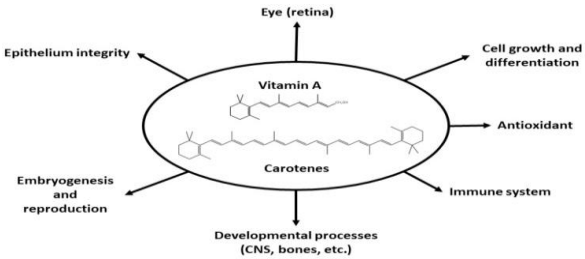


Figure 2: A schematic representation of the physiological roles in which vitamin A is involved
Vitamin A Deficiency

Vitamin A intake recommendations differ based on age and are typically expressed as retinol activity equivalents (RAE). One RAE is equivalent to 1 μg of retinol, 12 μg of β-carotene, or 24 μg of α-carotene or β-cryptoxanthin(86). For infants and children, the recommended intake is approximately 400–500 RAE. Adult males are advised to consume 900 RAE daily, while for females, including pregnant and lactating women, the recommended intake ranges from 700 to 1300 RAE, with the highest requirement for lactating women. Sufficient vitamin A is crucial for proper fetal development and later for the adequate nutrition of the newborn(87).

Vitamin B:

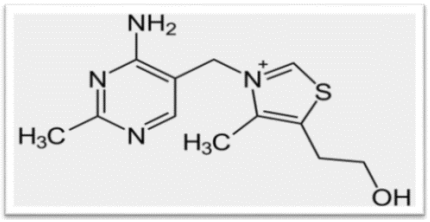
B vitamins are generally synthesized by plants, with their production in plant chloroplasts, mitochondria, and the cytosol tightly regulated to meet the plant's changing needs(78). Within plants, these vitamins perform the same cellular functions that they later fulfill in animals that consume them. However, vitamin B12 is an exception, as it is synthesized by bacteria and typically obtained from animal-derived foods, with synthesis occurring, for example, in the foregut of ruminant animals(2).

There are eight distinct B vitamins, each serving a unique function:
- Thiamin (Vitamin B1)
- Riboflavin (Vitamin B2)
- Niacin (Vitamin B3)
- Pantothenic Acid (Vitamin B5)
- Pyridoxine (vitamin B6)
- Biotin (Vitamin B7)
- Folate (Vitamin B9)
-Cyanocobalamin (vitamin B12)
Together, these are referred to as the vitamin B complex.

Mechanisms of Action and Functions of B Vitamins:

B vitamins serve as coenzymes in a significant portion of enzymatic processes that are essential for cellular physiological functions. In their role as coenzymes, the biologically active form of the vitamin binds to a protein "apoenzyme," forming a "holoenzyme," which enhances the enzyme's ability to catalyze a wider range of reactions(88). B vitamins are therefore critical in supporting many cellular activities. For instance, the main bioactive form of vitamin B6, pyridoxal 5′-phosphate, acts as a crucial cofactor for more than 140 enzymes involved in amino acid(89) synthesis, degradation, and conversion. Similarly, the active coenzyme form of pantothenic acid, coenzyme A (CoA), is necessary for about 4% of all mammalian enzymes(90).B vitamins often appear together in the same foods, and most people can meet their B vitamin needs by consuming a variety of nutrient-rich food(2).

Vitamin B1 (Thiamine)

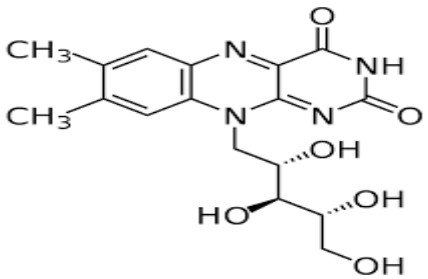


Vitamin B1 is a crucial component of the coenzyme thiamine pyrophosphate, which plays a vital role in

cellular energy metabolism pathways, including the pentose phosphate pathway and the tricarboxylic acid cycle (Krebs cycle). Thiamine is specifically involved in the oxidative decarboxylation of alpha-keto acids, which includes the conversion of pyruvate to acetyl-CoA, a key step in energy production. It also acts as a cofactor for transketolase, the enzyme responsible for catalyzing the transfer of two-carbon units during glucose oxidation in the hexose monophosphate pathway (3).

Vitamin B1 deficiency is common in individuals suffering from chronic alcoholism and malnutrition. A deficiency in this vitamin can lead to beriberi, a condition that impacts the heart and nervous system. Symptoms include cyanosis, peripheral neuropathy, tachycardia, paralysis of the lower extremities, and, if untreated, can progress to heart failure and eventually death (4).Without thiamine pyrophosphate, pyruvate cannot enter the tricarboxylic acid cycle, depriving the heart muscle of energy and leading to cardiac failure.

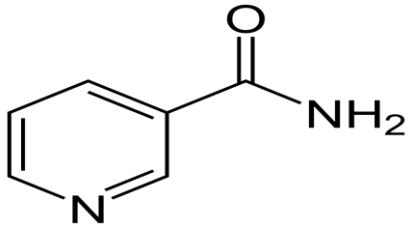
Vitamin B2 (Riboflavin):



Flavin adenine dinucleotide (FAD) and flavin mononucleotide (FMN) are coenzymes derived from riboflavin. These coenzymes act as redox cofactors, playing a critical role in cellular redox reactions by functioning as hydrogen acceptors and donors (5).In the mitochondrial electron transport chain, FAD accepts two hydrogen atoms from FADH2 and transfers them to oxygen, forming water. This process helps regenerate FAD, and for each cycle of transport, two molecules of ATP are produced.

Riboflavin deficiency is uncommon and usually occurs alongside deficiencies of other B vitamins. After prolonged periods of deficiency, symptoms such as photophobia (sensitivity to light), tearing, soreness, and burning in the lips, mouth, and tongue, as well as dermatitis, can manifest. In some cases, deficiency may also lead to peripheral neuropathy.

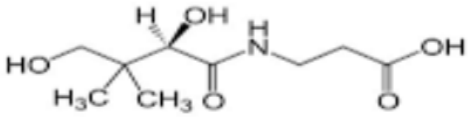
Vitamin B3 (Niacin)



Nicotinamide adenine dinucleotide (NAD) and phosphate nicotinamide adenine dinucleotide (NADP) are two essential coenzymes that contain niacin. These coenzymes are crucial for numerous enzymatic activities in cells, particularly in the metabolism of glucose, lipids, and alcohol. NAD plays a key role in transporting hydrogens and electrons during metabolic reactions, including the transfer from the tricarboxylic acid cycle (Krebs cycle) to the electron transport chain, functioning similarly to the coenzyme FAD.

The early signs of niacin deficiency include anorexia, muscle weakness, dyspepsia (indigestion), and a cutaneous rash. Digestive issues can lead to irritation and inflammation of the mucous membranes in the mouth and gastrointestinal tract. A severe deficiency of niacin results in pellagra, known as the disease of the "3 Ds": diarrhea, dermatitis, and dementia. Without treatment, pellagra can be fatal. The dermatitis associated with pellagra can be pigmented and desquamative (peeling). Central nervous system symptoms include confusion, neuritis,and disorientation (6).

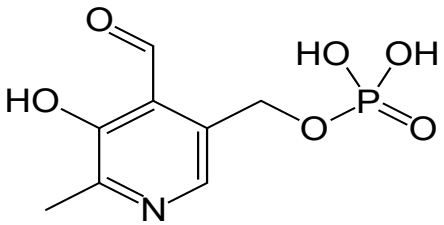
Vitamin B5 (Pantothenic Acid)



Pantothenic acid plays an essential role in the synthesis of lipids, hemoglobin, steroid hormones, and neurotransmitters within cells. It is a key component of Coenzyme A (CoA) and acyl carrier protein (ACP), both of which are involved in acylation processes crucial for metabolism. Pantothenic acid is found in a wide variety of foods, so deficiency is rare, typically occurring only in cases of malnutrition or among individuals taking pantothenic acid antagonists. Symptoms of deficiency include fatigue, depression, exhaustion,

weakness, insomnia, and paresthesia (tingling) in the fingers and soles of the feet (7).

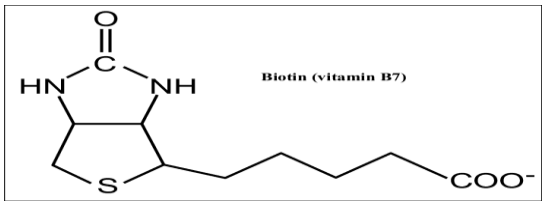
Vitamin B6 (Pyridoxine)



Pyridoxal phosphate, the active form of vitamin B6, acts as a cofactor for many enzymes involved in non-essential amino acid production and the metabolism of proteins and urea. It facilitates the transfer of amino groups and plays a key role in the synthesis of heme, nucleic acids, and in converting tryptophan into niacin or serotonin (8). Additionally, vitamin B6 is involved in the release of glucose from glycogen, the formation of myelin sphingolipids in nerve cells, and the modulation of steroid hormone receptors.

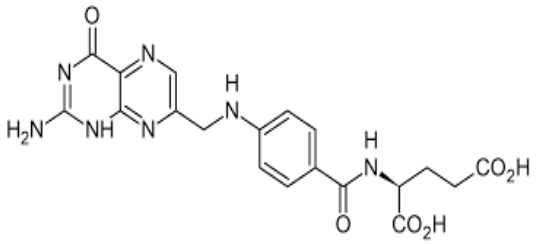
Although vitamin B6 is widely available in nature and stored in muscle tissue, deficiencies can occur, particularly due to interactions with certain medications. Deficiency symptoms include weakness, insomnia, irritability, and peripheral neuropathies (9).

Vitamin B7 (Biotin)



Biotin serves as a coenzyme, facilitating the transfer of carbon dioxide in metabolic reactions. It is vital for the tricarboxylic acid (TCA) cycle, as it helps transfer carboxyl groups from pyruvate. Biotin also plays an important role in fatty acid synthesis, gluconeogenesis, and the catabolism of fatty acids and amino acids.Deficiencies are rare because biotin is widely distributed in food and can be synthesized by intestinal bacteria and absorbed in the colon. Symptoms of biotin deficiency include loss of appetite, seborrheic dermatitis, nausea, hallucinations, baldness, depression, and fatigue (10).

Vitamin B9 (Folic Acid):

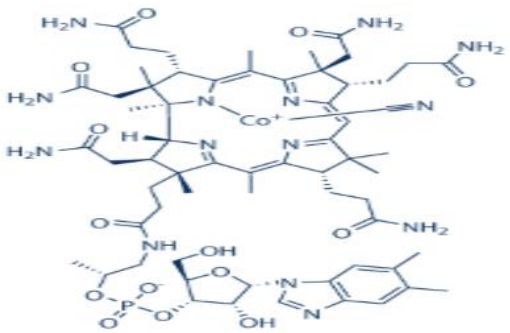


In recent years, extensive research has highlighted the crucial role of folate in human health. Folates can be found in various forms, including dihydrofolates, methyl folates, polyglutamyl folates, and monoglutamyl folates in foods (11).Folic acid acts as a methyl group donor and is essential for DNA synthesis, particularly in rapidly dividing cells. The active form of folate is tetrahydrofolic acid.

A deficiency in folic acid can lead to megaloblastosis in intestinal cells and macrocytic anemia. Additionally, folate deficiency is associated with hyperhomocysteinemia, characterized by elevated levels of homocysteine, which is linked to a heightened risk of coronary vascular disease and stroke. In pregnant women, a lack of folic acid can result in neural tube defects in infants, such as spina bifida and anencephaly. Elevated plasma homocysteine levels have also been correlated with Alzheimer's disease (12).

Supplementation with high doses of vitamins B6 and B12, along with folate, has been shown to lower plasma homocysteine levels in affected patients (13).

Vitamin B12 (Cyanocobalamin):



The activity of vitamin B12 is closely interconnected with the methylation cycle. Folates play a critical role in activating vitamin B12 by donating a methyl group. Both folates and vitamin B12 are essential for regenerating the amino acid methionine, which is vital for the production of S-adenosylmethionine (SAM) and for DNA synthesis (7).A deficiency in vitamin B12 can severely impact cell division,

particularly affecting cells in the bone marrow and the intestinal mucosa. This disruption leads to impaired erythrocyte mitosis, resulting in the formation of abnormally large cells and immature erythrocytes, culminating in a specific type of anemia known as megaloblastic anemia. Additionally, individuals with vitamin B12 deficiency may experience progressive neuropathy characterized by neural demyelination. Symptoms can include burning sensations in the feet, numbness, stiffness, tingling, and overall weakness.

Vitamin B Deficiencies:

There is a common assumption that populations in developed countries receive adequate nutrition and are therefore not deficient in essential micronutrients. To promote sufficient nutrition, governments usually establish a set of “dietary reference intakes” or similar guidelines for various nutrients. These guidelines often include a “recommended dietary allowance” (RDA), which represents the minimum daily intake of a nutrient considered sufficient to meet the nutritional needs of most healthy individuals. However, “meeting the requirements” typically means preventing chronic, nutrition-related diseases or deficiency disorders associated with a particular nutrient.

RDAs are based on population statistics and provide rough estimates of the average nutrient needs within a group, accounting for individual variations. However, for many micronutrients, precise data required to accurately determine daily needs are either lacking or incomplete. As a result, the recommendations are based on various assumptions and considerations, which can lead to significant variability in the final RDA values(91,92).

Vitamin C:

In 1970, Pauling (14) remarked that "Ascorbic acid is a vital nutrient for humans. Individuals who do not obtain ascorbic acid (vitamin C) can become ill and ultimately face fatal consequences.

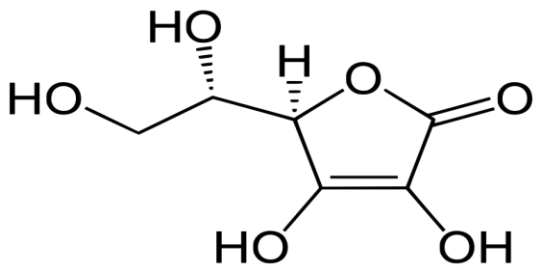
Vitamin C Sources:

Vitamin C is synthesized naturally only in non-human species, including certain primates, guinea pigs, fish, and birds (15). While most animals can produce their own vitamin C, humans possess a mutation in the DNA that encodes the enzyme gulonolactone oxidase, which is crucial for the synthesis of ascorbic acid (16) As a result of this mutation, obtaining vitamin C from external sources becomes essential (17).

For humans, the primary sources of vitamin C are fruits and vegetables. Citrus fruits, along with others like cantaloupe, watermelon, berries, pineapple, strawberries, cherries, kiwi, mangoes, and tomatoes, are particularly abundant in vitamin C. Additionally, vegetables are significant sources of this vitamin due to their higher content and year-round availability. Some of the key vegetables rich in vitamin C include cabbage, broccoli, Brussels sprouts, bean sprouts, cauliflower, mustard greens, peppers, peas, and potatoes (18).

Chemical Structure of Ascorbic Acid:

Vitamin C, commonly referred to as l-ascorbic acid, is also known by various other names, including ascorbate and the antiscorbutic vitamin. The l-ascorbic acid molecule consists of six asymmetrical carbon atoms ($C_6H_8O_6$) and has a structural relationship to glucose.(Chemical structure of Vitamin C)(19,20).



Chemical structure of vitamin C

Vitamin C Function:

Role in immune system and inflammation:

Vitamin C plays a crucial role in supporting a healthy immune system, and its deficiency can lead to immune dysfunction and increased susceptibility to infections. During bacterial infections, the levels of ascorbic acid in various bodily fluids decrease. As a result, it is often utilized as a supplementary treatment for various infectious diseases, including hepatitis, HIV, influenza, and periodontal diseases(21).

Ascorbic acid enhances the phagocytic function and activity of several immune cells, including neutrophils, natural killer cells, macrophages, and

lymphocytes. It also stimulates lymphocyte proliferation and boosts antibody production(22,23)

Vitamin C Deficiency:

Scurvy, a condition caused by vitamin C deficiency, is characterized by impaired wound healing and the failure of fractured bones to mend. This occurs due to the lack of collagen formation, which is crucial for tissue repair. Scurvy can develop when the body's vitamin C reserves are reduced to one-fifth of their normal level. The necessary body reserve and required dosage of vitamin C depend on body weight(24)

Symptoms of scurvy include general weakness, swelling in the legs and arms, hemorrhages in the nose, skin, and gums, infections, and damage to bones and cartilage (osteoporosis). Other complications can include vasculitis and cardiomegaly [164]. Various forms of bleeding are observed, such as petechiae, subperiosteal hemorrhage, ecchymoses, purpura, bleeding gums, and hemarthrosis(25).

Vitamin D:

Vitamin D is a fat-soluble vitamin that functions as a steroid hormone, playing a key role in various bodily systems, including the bones, intestines, immune and cardiovascular systems, pancreas, muscles, and brain. It also helps regulate the cell cycle. One of its primary functions is to enhance the absorption of calcium, magnesium, and phosphate in the intestines, along with other important biological effects. In humans, the most significant forms of vitamin D are vitamin D3 (cholecalciferol) and vitamin D2 (ergocalciferol) (26).
Vitamin D insufficiency or deficiency (VDD) is highly prevalent in the general population, with some researchers referring to it as a "vitamin D deficiency epidemic" or even a "pandemic" (27, 28)

Challenges in Evaluating the Impact of Vitamin D Supplementation Health Outcomes

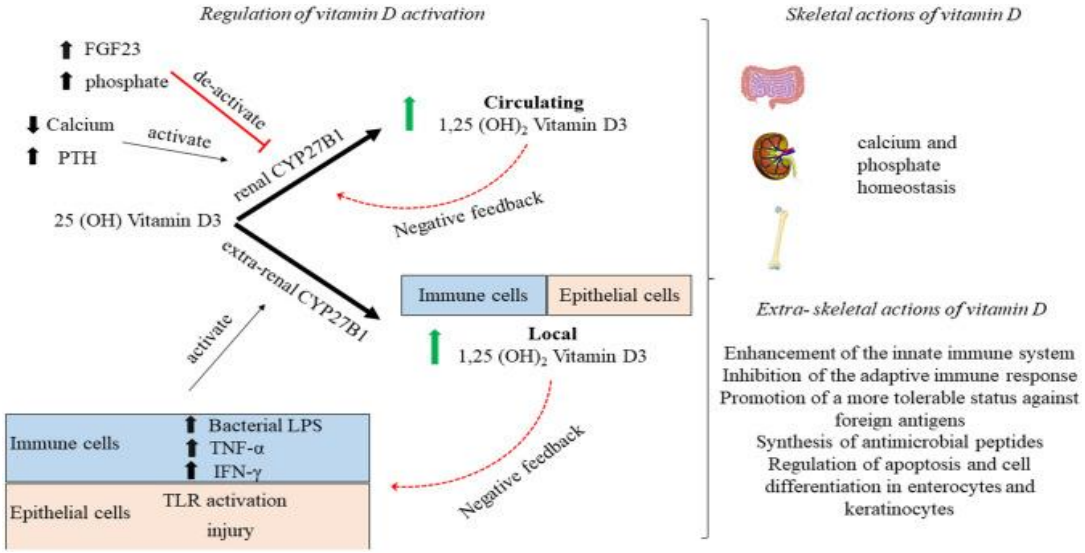
Although vitamin D is a nutrient, its levels are primarily determined by skin synthesis after sunlight exposure, making it difficult to accurately assess the effects of supplementation. Placebo-controlled randomized controlled trials (RCTs) examining vitamin D's impact on health outcomes differ significantly from standard drug trials, as it's impossible to completely prevent vitamin D intake or sunlight exposure in placebo groups (29). Additionally, given the widespread prevalence of vitamin D deficiency, some RCTs, such as the large VITAL study (30,31), permit low-dose vitamin D supplementation even In the placebo group.

Regulation of Vitamin D

Vitamin D exists in two primary forms: vitamin D2 (ergocalciferol) and vitamin D3 (cholecalciferol). Vitamin D2 is mainly obtained through the diet from fungi and plants, while vitamin D3 comes from animal products or is synthesized in the skin from the cholesterol precursor 7-dehydrocholesterol when exposed to adequate ultraviolet B (UVB) radiation. Efficient vitamin D synthesis through sun exposure occurs only when the sun's angle is greater than 45°. Consequently, people living in the northern hemisphere often do not receive sufficient sunlight for vitamin D production during the winter months, with some regions experiencing insufficientexposure for up to six months a year (32).

Additionally, the typical Western diet is generally low in vitamin D (33) To address this deficiency, some countries have implemented policies to fortify dairy products (34,35) and margarine (36)with vitamin D, while artificial UVB light bulbs are also used as a method to stimulate vitamin D synthes.

Low plasma calcium or phosphate levels regulate parathyroid hormone (PTH) and fibroblast growth factor 23 (FGF-23), which stimulate the 1α-hydroxylation of 25(OH)D in the kidneys, specifically in the mitochondria of proximal convoluted tubule cells, by the enzyme 1-hydroxylase (CYP27B1). This process leads to the production of active vitamin D (1,25(OH)2D)(37).



(Fig. 3). Additionally, 1α-hydroxylation can occur in extrarenal tissues, including epithelial tissues, placenta, bone, endocrine glands, brain, liver endothelium(38,39),and especially in immunecells(40).

Biological importance:

Vitamin D deficiency has been linked to an increased risk of elevated blood sugar levels and diabetes (41). Vitamin D plays a crucial role in the maturation of white blood cells, which are essential for immune responses. Additionally, a consistent association has been observed between vitamin D deficiency and a higher risk of respiratory infection(42). Since the 1980s, vitamin D deficiency has been on the rise, largely due to increased sunscreen use and reduced sun exposure (43).

Vitamin D, Muscle Strength, Muscle Mass, Muscle Power, and Risk of Falls:

Vitamin D deficiency has been linked to musculoskeletal dysfunction, including decreased muscle strength and mass, as well as an increase in intramuscular non-contractile tissue (44,45).

Vitamin E:

Vitamin E refers to a group of fat-soluble compounds, first discovered by Evans and Bishop in 1922, known for their distinct antioxidant properties that are vital for maintaining health.(46) It is found in fat-containing foods,(47) and due to its fat-soluble nature, vitamin E can be stored in the fatty tissues of both animals and humans, reducing the need for daily consumption. The vitamin E family, known as tocochromanols, includes tocopherols and tocotrienols—both of which encompass tocol and tocotrienol derivatives that exhibit the biological activity of d-alpha-tocopherol.

Vitamin E content in vegetable oils

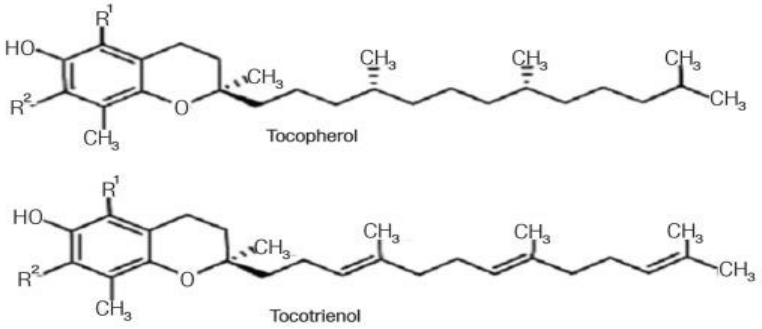
Oil	Alpha-tocopherol	G-tocopherol	D-tocopherol	A-tocotrienol
coconut	0.5	0	0.6	0.5
Maize (corn)	11.2	60.2	1.8	0
Palm	25.6	31.6	7.0	14.3
Olive	5.1	Trace amounts	0	0
Peanut	13.0	21.4	2.1	0
soyabean	10.1	59.3	26.4	0
Wheatgerm	133.0	26.0	27.1	2.6
Sunflower	48.7	5.1	0.8	0

Table: 2 Source: Slover HT. Tocopherols in foods and fats.(48)

Chemistry of Vitamin E

The term ‘tocopherol’ signifies the methyl-substituted derivatives of tocol and is not synonymous with the term ‘vitamin E’. Natural tocochromanols comprise two homologous series: tocopherols with a saturated side chain and

tocotrienols with an unsaturated side chain. Tocopherols andtocotrienols have the same basic chemical structure, which is characterised by a long isoprenoid side chain attached at the 2 position of a 6-chromanol ring, as shown in structure tocopherols and tocotrienol.



R^1	R^2	
CH_3	CH_3	α
CH_3	H	β
H	CH_3	γ
H	H	δ

The structures of a tocopherol and tocotrienol.

Adapted from: Colombo ML. An update on vitamin E, tocopherol and tocotrienol: Perspectives.(49)

Functions of Vitamin E:

Prevention of Oxidative Stress

Vitamin E is a powerful chain-breaking antioxidant that helps prevent the formation of reactive oxygen species during the oxidation of fats and the propagation of free radical reactions.(50)It is primarily found in the cell and organelle membranes, where it offers its strongest protective effect, even when present in low concentrations—about one molecule per 2,000 phospholipid molecules. As the first line of defense against lipid peroxidation, vitamin E protects cell membranes from free radical damage Studies have shown that a mixture of tocopherols is more effective at inhibiting lipid peroxidation in human erythrocytes than alpha-tocopherol alone(51) Due to its peroxyl radical-scavenging properties, vitamin E also shields polyunsaturated fatty acids in membrane phospholipids and plasma lipoproteins(52).Tocopheroxyl radicals formed during this process can either: (1) oxidize other lipids; (2) undergo further oxidation to produce tocopherylquinones; (3) form non-reactive tocopherol dimers by reacting with another tocopheroxyl radical; or (4) be reduced back to tocopherol by other antioxidants.

Regulation of Platelet Aggregation and Protein

Kinase C Activation

Elevated concentrations of alpha-tocopherol in endothelial cells have been shown to inhibit platelet aggregation and stimulate the release of prostacyclin from the endothelium. This effect is thought to result from the downregulation of intracellular cell adhesion molecule (ICAM-1) and vascular cell adhesion molecule (VCAM-1), which reduces the adhesion of blood cells to the endothelium. Additionally, vitamin E enhances the arachidonic acid cascade by increasing the expression of cytosolic phospholipase A2 and cyclooxygenase-1, leading to a greater release of prostacyclin, a potent vasodilator and inhibitor of platelet aggregation in humans(53,54,55)Some studies also suggest that tocopherols may inhibit platelet aggregation through the suppression of protein kinase C (PKC) activity and the enhancement of nitric oxide synthase action(56,57).

Vitamin E Deficiency and Its Effects

The(58) wild-type alpha-TTP was found to bind phosphatidylinositol phosphates (PIPs), whereas its arginine mutants did not. PIPs in the target membrane facilitate the inter-membrane transfer of alpha-tocopherol by alpha-TTP. Symptoms of vitamin E deficiency include muscle weakness, vision problems, changes in the immune system, numbness, difficulty walking, tremors, and poor balance. Additionally, deficiency can lead to neuromuscular issues such as spinocerebellar ataxia, myopathies, dysarthria, loss of deep tendon reflexes, diminished vibratory sensations, and a positive Babinski reflex.24 Vitamin E deficiency may also result in anemia due to oxidative damage to red blood cells, retinopathy,(60,61) and a weakened immune response.If left untreated, it can cause blindness, heart disease, permanent nerve damage, cognitive impairment, and in some cases, male infertility.(59)

Vitamin k

Vitamin K is a fat-soluble vitamin essential for blood clotting. It was discovered in 1929 by Danish scientist Henrik Dam in Germany and was named "K" after the German word "Koagulation," as the earliest research was published in a German journal. The pure form of vitamin K1 was isolated from alfalfa in 1939, and soon after, it was found that a second form, vitamin K2, with a more unsaturated side chain, is synthesized by bacteria (62).

Both vitamin K1 and K2 occur naturally, mainly in green leafy vegetables, and are absorbed in the small intestine. Adequate dietary fat and bile acid production in the liver are crucial for their absorption. Like other fat-soluble vitamins, K1 and K2 are initially carried by chylomicrons (CMs) into the lymphatic system before entering circulation. The synthetic form, vitamin K3, is water-soluble and does not require bile acids for absorption; it moves directly from the intestinal mucosal cells into the liver via portal circulation (63). The liver serves as the main storage site for vitamin K.

Types and Sources of Vitamin K

Vitamin K exists in three main forms: K1, which is derived from plants; K2, produced by bacteria or through fermentation; and K3, a synthetic form (64,65). Naturally, vitamin K is found as vitamin K1 (phylloquinone, PK) and vitamin K2, which includes various compounds known as menaquinones (MKs). Menaquinones, a subgroup of vitamin K2, are characterized by their unsaturated side chains, which contain between 1 and 13 isoprene residues.

Vitamin K2 is also found in fermented foods, such as cheese and the Japanese soy product "Natto" (66,6 7). Additionally, there is a synthetic form of vitamin K known as menadione (2-methyl-1,4-naphthoquinone nucleus), which serves as a structural precursor to both vitamins K1 and K2. However, the use of menadione as a supplement is prohibited by the FDA due to its toxicity (65).

Pharmacokinetics of Vitamin k

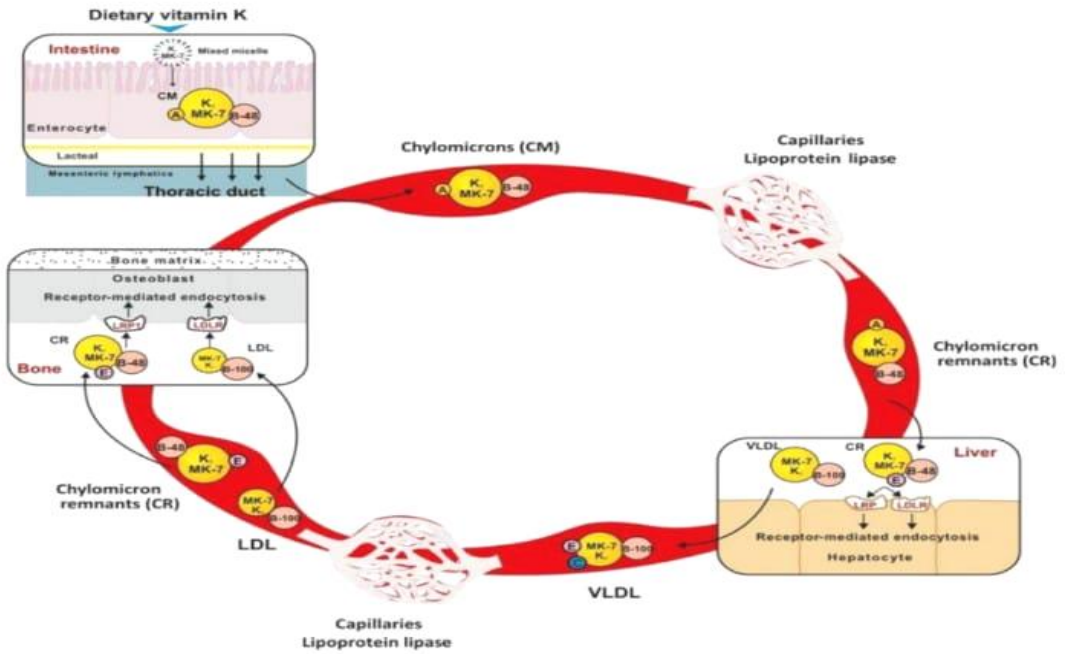


Figure 4. Schematic diagram of dietary phylloquinone(K1) and menaquinone-7 (MK-7) absorption, transportation, and cellular up take .

Vitamin K is converted within the cell to its reduced form, known as vitamin K hydroquinone, through the action of the enzyme vitamin K epoxide reductase (VKOR) (67). Another enzyme, gamma-glutamyl carboxylase, also referred to as vitamin K-dependent carboxylase, then oxidizes vitamin K hydroquinone, facilitating the carboxylation of glutamic acid (Glu) to gamma-carboxyglutamic acid (Gla) (68).

Mechanisms of action of vitamin k

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Deficiency of vitamin k

Children: Osteocalcin is one of the most prevalent proteins in the body and is found at levels at least ten times higher during periods of growth compared to when peak bone mass is reached. This indicates that children have a significantly greater need for vitamin K than adults. Unfortunately, the increasing consumption of snacks and fast food has resulted in a decline in vitamin K intake among children year after year (71)

Early Infancy: There is a critical period from conception to six months during which a human baby is at risk of life-threatening bleeding due to insufficient vitamin K. Late-onset vitamin K deficiency bleeding, which typically occurs between three to eight weeks of age, can result in death or permanent neurological damage in infants, primarily due to intracranial hemorrhaging. This poses a significant nutritional risk for infants who are predominantly breastfed (72).

Bile acid sequestrant drugs such as cholestyramine (Questran®) and colestipol (Colestid®) are used by some individuals to lower cholesterol levels in the blood. However, these medications can significantly reduce the body's absorption of vitamin K, especially when taken over an extended period (73).
Orlistat (Alli® and Xenical®) is a weight-loss medication that decreases fat absorption in the body, which can also lead to reduced absorption of vitamin K (74).

Age	Male	Female	Pregnant	Lactating
0-6 months	2.0 mcg	2.0 mcg		
7-12 months	2.5 mcg	2.5 mcg		
30 mg	30 mg			
55 mcg	55 mcg			
60 mcg	60 mcg			
14-18 years	75 mcg	75 mcg	75 mcg	75 mcg
19-50 years	120 mcg	90 mcg	90 mcg	90 mcg
51-70 years	120 mcg	90 mcg		
70 + years	120 mcg	90 mcg		

Table 3. Amount of vitamin K needed in different groups of people

Vitamins	Males daily value	Female Daily Value	Pregnant Daily Value	Breastfeeding Daily Value
Vitamin A	1000 µg/d	800 µg/d	800 µg/d	1300 µg/d
Vitamin B1	1.5 mg/d	1.1 mg/d	1.5 mg/d	1.6 mg/d
Vitamin B2	1.7 mg/d	1.3 mg/d	1.6 mg/d	1.8 mg/d
Vitamin B3	19 mg/d	15 mg/d	17 mg/d	20 mg/d
Vitamin B5	10 mg/d	9.0 mg/d	10 mg/d	12 mg/d
Vitamin B6	2.0 µg/d	1.6 µg/d	2.2 µg/d	2.1 µg/d
Vitamin B7	30 µg/d	30µg/d	40 µg/d	60 µg/d
Vitamin B9	400 µg/d	400 µg/d	400 µg/d	600 µg/d
Vitamin B12	2.0 mg/d	2.0 mg/d	2.2 mg/d	2.6 mg/d
Vitamin C	60 mg/d	60 mg/d	70 mg/d	95 mg/d
Vitamin D	5.0 µg/d	5.0 µg/d	10 µg/d	10 µg/d
Vitamin E	10 mg/d	8.0 mg/d	10 mg/d	12 mg/d
Vitamin K	70 µg/d	60 µg/d	65 µg/d	65 µg/d

Table:4.Recommended Dietary Allowances (RDA) for Vitamins

CONCLUSION

To conclude, vitamins are essential to the human body and can be categorized into two types: water-soluble and fat-soluble vitamins. Both types play critical roles in maintaining overall health. The importance of these vitamins is undeniable across all age groups, and a deficiency can lead to serious health issues in specific parts of the body, depending on the particular vitamin, the individual's age, and health status. Despite their significant impact, vitamins are needed only in small quantities, so the daily requirement is typically low. Vitamin deficiency occurs when a vitamin is absent for a prolonged period. A primary deficiency results from inadequate intake of a vitamin, while secondary deficiency occurs due to health conditions, such as malabsorption. On the other hand, hypervitaminosis refers to the excessive accumulation of fat-soluble vitamins in the body's tissues, typically due to excessive intake.

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