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EFFECTS OF VITAMIN AND MINERAL NUTRITURE ON SYSTEMIC AND VISUAL FUNCTION: A REVIEW

By
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ABSTRACT

Vitamins and minerals are essential for all aspects of human function. There is, however, considerable controversy regarding the types and quantities of these nutrients needed to insure maximum performance. In this paper, basic nutritional concepts are reviewed, specific information is presented on selected vitamins and minerals, and the effects of vitamin and mineral nutriture on visual function is discussed. It is concluded that, apart from diseases associated with frank deficiencies or toxic levels, relatively little is known about how vitamin and mineral levels can contribute to optimum visual performance.

KEY WORDS

Nutrition, vitamin, mineral, vision, health, physiology, supplementation.

INTRODUCTION

Few areas of health care are so important and yet so poorly understood as nutrition. In the space of a few decades, the concept of a "balanced diet" has undergone major revision, and the "four basic food groups" have been replaced by the U. S. Department of Agriculture's Food Guide Pyramid.[1] With respect to vitamin and mineral nutriture, recommendations have drifted between avoidance of any vitamins not obtained in food to the suggestion that everyone needs a daily supplement. Some nutritionists argue that people should meet all of their nutritional needs by carefully selecting foods, and they suggest that supplementation is bad because the vitamins in pills are "un-natural." Others recommend megadoses of vitamin C to prevent illness, and the use of antioxidant vitamin and mineral supplements (e.g., beta-carotene, vitamins C and E, zinc, and selenium) to prevent some cancers[2,3] and ocular problems such as age related macular degeneration (ARMD)[4,5] and cataracts.[6]

Changes in nutritional recommendations have left many health care providers confused, and their patients find themselves assaulted by the conflicting claims from those with "back-to-nature," regulatory, manufacturing, and scientific orientations. It is clear that extreme deficiencies can produce specific diseases like scurvy or rickets, but an understanding of how sub-optimum nutriture can subtly affect physiology and performance is just beginning to emerge.

To further confuse matters, new discoveries are changing the way some formerly benign vitamins and minerals are regarded. For example, iron supplementation has long been regarded as desirable, especially for young women, but recent evidence has linked iron levels in the body to the development of vascular problems.[7]

If the conflicting claims about vitamin and mineral efficacy are not enough to bewilder patients, recommendations about required quantities certainly are. Most vitamin and mineral supplement bottles have labels that list the U. S. Food and Drug Administration recommended daily allowances (RDAs). These allowances are based on a report published in 1968.[8] Unfortunately, the RDAs have not been updated to reflect the latest research,[8] and this has created inconsistencies in the recommended nutrient amounts and in the units used to measure the nutrients.

Currently RDAs are defined as "...the levels of intake of essential nutrients...adequate to meet the known nutrient needs of practically all healthy persons."[8] Based on this definition, many researchers suggest that the RDAs really only relate to preventing diseases like scurvy, while the maintenance of optimum health and performance require much higher levels of some vitamins and minerals. Others point out that it is useless to establish universal intake levels for vitamins and minerals because there is no guarantee that all people need the same quantities. There may also be significant individual differences in the ability of people to transfer vitamins and minerals from the digestive tract to the parts of the body where they are needed. In addition to these problems, different forms and combinations of vitamins and minerals can have very different bioavailabilities.

If the area of nutrition is as complex and confusing as it seems, is there any point in reviewing it? Are there enough basic and reasonably well accepted scientific data to help explain the effects of vitamin and mineral nutriture on visual health and performance? And, are there enough good data to use as a basis for patient recommendations? The answer to these questions is a qualified "maybe."

The weight of evidence now suggests the antioxidant vitamins and minerals can be effective in the management and/or prevention of certain eye diseases,[4-6,9] but this "good news" is tempered by other information indicating that many patients do not even consume the RDAs of vitamins and minerals.[10] As these data emerge, more and more optometrists are becoming concerned about their patients' nutriture, and some are recommending supplementation for them. To make such recommendations, however, an understanding of basic aspects of nutrition, and the effects of sub-optimum nutrition on vision is required. In this paper, the general topic of nutrition will be reviewed briefly, specific information on vitamins and minerals will be presented, and the effects of vitamin and mineral nutriture on visual function will be discussed.

BASIC NUTRITIONAL CONCEPTS

Nutrition usually refers to the use of substances consumed to maintain life. These substances can be divided into several groups on the basis of their chemistry and the way in which the body uses them. The essential nutrients are discussed in many references such as Modern

Nutrition in Health and Disease,[11] Recommended Dietary Allowances,[8] and the Encyclopedia of Medicine.[12] The material presented below is derived from these general sources unless specifically referenced.

Water

Water is an important but often overlooked essential nutrient. It is a crucial component in many cellular metabolic processes. It also maintains blood volume, and facilitates the passage of material through the digestive system. Dehydration can be a rapid and lethal process that occurs when an adequate supply of water either is not ingested, or is not maintained in the body. Given an adequate water intake, however, healthy persons closely regulate their hydration levels through a complex process involving thirst, excretion, and substances including salts and hormones that regulate the amount of water stored in the tissues and blood.

Fiber

Fiber is also an essential component of the diet. It is not digested during its passage through the gastrointestinal (GI) tract, but it serves to provide the bulk that facilitates proper functioning of this tract. Fiber in the diet comes mainly from the structural material in plants that are ingested. High fiber diets are presumed to be beneficial because fiber speeds the passage and elimination of material through the GI tract, and this reduces the time during which toxic substances can be produced and/or absorbed.

Fat

Recently, dietary fat has come under heavy criticism; comments such as "eating fat will make you fat" abound in the popular literature. Many nutritional experts caution against the consumption of too much fat and some suggest that fat should constitute less than 25% of the calories consumed.[13] In the body, fat is burned for energy and is made into cellular components. It is also stored for use during times of reduced food availability. This storage mechanism has proven to be a two-edged sword for humans. In environments where food shortages can occur, stored fat can be life saving, but in modern countries with an abundance of food, excessive stored fat can be life threatening by increasing the risk of diabetes, heart disease, and other problems. The process by which the body decides to use, store, or eliminate fat is complex and has resisted the efforts of many scientists to understand and control it.

Based on the number of double bonds between carbon molecules, dietary fat can be classified as saturated (meat and dairy products), monosaturated (some plant oils such as olive oil), or unsaturated (fish and many vegetable oils). Saturated fats can raise the level of cholesterol and low density lipoproteins (the "bad" kind) in the blood, whereas mono- and unsaturated fats can have the opposite effect.

Protein

Protein often enters the diet along with fat; main sources include flesh foods, dairy products, and eggs. Within the body proteins are used for growth and regeneration of tissues and organs. Proteins are made from groups of amino acids; 20 separate amino acids are used in the human body. Twelve of the amino acids can be manufactured by the body, but 8, called the essential amino acids, must be supplied from the diet. Lack of sufficient dietary protein is not a major problem for most healthy adults in modern countries, but it can be a problem in developing countries, for children experiencing rapid growth, or for those on unusual diets (e.g., crash weight loss or strict vegan diets).

Carbohydrates

Chemically, carbohydrates include sugars and starches that the body burns as relatively quick sources of metabolic energy. Many nutritionists now urge the consumption of more dietary carbohydrates, and some suggest that a proper diet should include about half of its calories from carbohydrates.[13] Typical sources of carbohydrate include grains, bread, pasta, vegetables, fruits, and sugar. Sometimes a distinction is made between unrefined and refined carbohydrate sources; unrefined sources include fruits, grains, etc. that combine the carbohydrates with substantial quantities of other nutrients such as fiber, vitamins, and/or minerals. Refined carbohydrates, such as table sugar, have these other nutrients removed and are therefore regarded as less desirable by nutritionists.

Vitamins and Minerals

In the body, vitamins serve to regulate metabolism, to facilitate the proper utilization of the other essential nutrients, and to assist in the quenching of free radicals. Some vitamins are also incorporated into substances that serve specialized functions (e.g., the use of vitamin A to form visual photopigments). Vitamins can be either water soluble (e.g., B

and C) or fat soluble (e.g., E). The water soluble vitamins are excreted more readily than the fat soluble vitamins, so they must be replaced on a more frequent basis.

The ability of some vitamins, especially C, E, and beta-carotene (a pro-form of vitamin A), to protect the body from free radical damage is a relatively new discovery. Free radicals are molecules that have lost an electron, and this makes them unstable and highly reactive.[14] To convert a free radical to a stable state, it must take an electron from another molecule. The molecule from which the electron was taken then becomes a free radical itself. This process can induce a cascade of biochemical reactions that leaves many molecules permanently altered or damaged. Free radical damage has been implicated in the development of some cancers, cataracts, age-related macular degeneration, and even aging.[2-6,9] The antioxidant vitamins protect the body against free radical damage by giving up electrons to the free radicals, thus quenching their activity, without becoming free radicals themselves.

Minerals are inorganic nutrients that serve many functions in the body. For example, calcium is incorporated into bones, iron is required for the formation of hemoglobin in the blood, and sodium helps to regulate fluid balance. Other minerals such as zinc and magnesium are responsible for maintaining and/or regulating cellular metabolism. Copper, zinc, selenium, and manganese are used for the formation of metalloenzymes such as superoxide dismutase, catalase, and glutathione peroxidase that are used along with the antioxidant vitamins to quench free radicals.

Because vitamins and minerals serve such important roles in the body, they will be discussed in more detail.

VITAMIN AND MINERAL NUTRITURE

Over 25 different vitamins and minerals are believed to be necessary for good health. Some of these substances must be consumed in significant quantities on a frequent basis, whereas others, like the trace minerals are needed in only minute amounts. As a guide to the appropriate quantities of each vitamin and mineral needed, the National Research Council has developed a list of recommended dietary allowances.[8] (Table 1) A healthy person whose diet includes these RDAs should not suffer any of the known vitamin or mineral deficiency diseases, but it is not clear whether the RDAs will insure optimum performance and body function.

Insert Table 1 About Here

Several of the vitamins and minerals with specific systemic or visual importance will be discussed individually. The material on the vitamins and minerals is derived from references including The Pharmaceutical Basis of Therapeutics,[15] Modern Nutrition in Health and Disease,[11] the Nutrition Almanac,[16] and Recommended Dietary Allowances.[8] Only information not found in these general sources.

Vitamin A (Retinol)

Retinol is a fat soluble vitamin found primarily in fish oils, liver, egg yolk, and whole milk. Precursors (also known as provitamins) of vitamin A occur in plants in the form of alpha-, beta-, and gamma-carotenes. Beta-carotene is a potent source of vitamin A because it can be cleaved to form two molecules of retinol. In the body, vitamin A is stored in the liver and then transported to the tissues where it is needed by a special retinol-binding protein.

Vitamin A is essential for normal growth, formation of strong teeth and bones, and for normal skin. It is also essential for the maintenance of mucus-secreting surfaces such as those found in the eye, respiratory, digestive, urinary tracts. With insufficient vitamin A, these surfaces loose their mucus-secreting cells and are converted to tough, hard (keratinized) tissues. This disrupts normal function and increases susceptibility to infection. Vitamin A is also necessary for vision. In the retina, the zinc-requiring enzyme, alcohol dehydrogenase, converts retinol to retinal that combines with proteins to make the photopigments

Liver reserves of vitamin A in the normal adult are sufficiently large to sustain the body during long periods of dietary deprivation. If deficiency does occur, it is usually due to failure to absorption of enough of the vitamin. This is sometimes seen in cystic fibrosis, bile duct obstruction, or treatment with lipid lowering drugs.

Prominent clinical findings of vitamin A deficiency are ocular and range from night blindness and conjunctival drying (xerosis) with foamy, white patches on the conjunctiva (Bitot's spots), through corneal drying, to corneal softening and opaqueness (keratomalacia). These findings are known collectively as xerophthalmia.

Other effects of vitamin A deficiency include dry, rough skin, loss of appetite, diarrhea, lowered resistance to infection and weak bones and teeth.

Three synthetic vitamin A-like compounds are available for the treatment of skin diseases: isotretinoin (13-cis retinoic acid)(Accutane™) is used to treat acne; etretinate (Tegison™) is used to treat psoriasis; and tretinoin (all-trans retinoic acid)(Retin-A™) is used to treat acne and skin changes caused by chronic sun exposure.

Prolonged excess intake of vitamin A can result in a toxic syndrome known as hypervitaminosis A. Signs and symptoms include lethargy, irritability, pain and tenderness in the bones, headache, and dry itchy skin. Intracranial pressure can also be increased, mimicking a brain tumor.

Beta-Carotene

Beta-carotene is an orange pigment found in vegetables and fruits such as carrots, winter squashes, broccoli and apricots. Although not specifically a vitamin, beta-carotene has several important functions in the body. It serves as a source of vitamin A and it is a potent, fat-soluble antioxidant. As an antioxidant, it helps to protect the unsaturated fats which form the body's cell membranes from free radical damage.

Excessive intake of beta-carotene (e.g., eating a huge quantity of carrots) does not cause hypervitaminosis A because the conversion of carotene to retinol is a limiting factor. Excessive consumption can, however, cause a yellow discoloration of the skin that is distinguished from jaundice by the absence of scleral pigmentation.

The B Vitamins

The vitamin B group is composed of 11 compounds that differ in chemical structure and biological action. They include thiamine (vitamin B_1), riboflavin (vitamin B_2), niacin, pantothenic acid, pyridoxine (vitamin B_6), biotin, folic acid, and cobalamin (vitamin B_{12}). The reason for grouping these different compounds as a single class was their original isolation from the same sources, notably liver and yeast. The B vitamins function in intermediary metabolism, with many of them helping in the metabolism of glucose for energy production. All B vitamins are water-soluble so they are not stored in the body for long periods.

Vitamin B_1 (Thiamine)

Thiamine is present in meat, yeast, whole grains, and nuts. In the body, it is converted to the coenzyme thiamine pyrophosphate (TPP) that is involved in the metabolism of carbohydrates. (A coenzyme is a substance that is required to facilitate the function of an enzyme.) This process results in consumption of thiamine, so the need for vitamin B_1 is greatest when the diet includes a large proportion of carbohydrates. Thiamine pyrophosphate is also involved in the normal function of nerves, muscles, and the heart.

Thiamine deficiency causes beriberi, a disease characterized by extensive damage to the nervous and circulatory systems, muscle wasting, and edema. Mild deprivation causes peripheral neuritis with sensory disturbances including localized areas of hyperesthesia or anesthesia. The neuritis can progress to loss of muscle strength and complete paralysis of a limb. Moderate deficiencies can cause cardiovascular symptoms including dyspnea on exertion, palpitation, tachycardia, and other abnormalities. There can also be extensive edema. Because thiamine deficiency can cause demyelination of the optic nerve and optic tract,[17] differential diagnosis of the demyelinating diseases must include the possibility of thiamine deficiency.

Alcoholism is the most common cause of thiamine deficiency in the United States. In addition to peripheral neuritis, toxic amblyopia, Wernicke's encephalopathy, and Korsakoff's syndrome can be consequences of alcoholism and thiamine deficiency. The ophthalmoplegia, nystagmus, ataxia, and confusion associated with Wernicke/Korsakoff syndrome usually responds to the administration of thiamine.

Vitamin B_2 (Riboflavin)

Riboflavin is found in milk, cheese, organ meats, eggs, green leafy vegetables, and whole-grain cereals, and breads. It is also produced by the bacteria in the intestine. In the body, riboflavin functions through two coenzymes: flavin mononucleotide (FMN) and flavin adenine dinucleotide (FAD). These coenzymes are essential for the metabolism of carbohydrates, fats, and proteins, and for the production of energy within the cells.

With riboflavin deficiency, sore throat and angular stomatitis generally appear first. Later, glossitis, cheilosis (red, denuded lips),

seborrheic dermatitis of the face, and dermatitis over the trunk and extremities occur, followed by anemia and neuropathy. In some cases, corneal vascularization, photophobia, decreased visual acuity, dryness, burning, and cataract formation can occur.[18] Supplementation with riboflavin typically results in resolution of the ocular complaints, although ghost vessels can persist in the cornea. Riboflavin deficiency is difficult to recognize because it rarely occurs in isolation and some of its signs are also seen other deficiencies and diseases.

Niacin (Nicotinic Acid)

Good sources of niacin include liver, meat, fish, poultry, whole grain breads, cereals, nuts and legumes. Niacin can also be synthesized in the body from the amino acid tryptophan. This helps to meet the daily requirement for niacin, but the rate of synthesis is inadequate to maintain good health.

In the body, nicotinic acid is converted to either nicotinamide adenine dinucleotide (NAD) or nicotinamide adenine dinucleotide phosphate (NADP). NAD and NADP are coenzymes involved in the metabolism of carbohydrates and fats. They also are important for proper nervous system function and in the maintenance of healthy skin.

Niacin deficiency can result in pellagra that is characterized by signs and symptoms involving the skin, gastrointestinal tract, and central nervous system. This forms a triad frequently referred to as dermatitis (an erythematous eruption resembling sunburn), diarrhea, and dementia, also known as the "three Ds." Pellagra occurs most frequently in chronic alcoholism, protein malnutrition, and multiple vitamin deficiencies.

Niacin is useful in the treatment of most forms of hyperlipoproteinemia, and can produce a reduction in plasma LDL-cholesterol. The usefulness of niacin for lowering LDL-cholesterol is limited by the frequent occurrence of side effects including an intense cutaneous flush and pruritus involving the skin on the face and upper part of the body.

Vitamin B_5 (Pantothenic Acid)

Panthothenic acid is ubiquitous in foods, but it is particularly abundant in organ meats, beef, and egg yolk. It is, however, easily destroyed by heat and alkali. In the body, pantothenic acid is necessary for the biosynthesis of coenzyme A that aids in the metabolism of

carbohydrates, in gluconeogenesis, and in degradation of fatty acids. It is also used in the synthesis of sterols, steroid hormones, and porphyrins.

Pantothenic acid deficiency is manifested by fatigue, headache, sleep disturbances, muscle cramps, and impaired coordination. Fortunately, there is little evidence of pantothenic acid deficiency in humans who consume a normal diet because this vitamin is found in so many foods.

Vitamin B_6 (Pyridoxine)

The name pyridoxine has been assigned to this vitamin, but two related natural compounds, pyridoxal and pyridoxamine, have been shown to possess the same biological properties. Pyridoxine is supplied by meat, liver, whole-grain breads, cereals, soybeans, and vegetables. Pyridoxine is sensitive to heat, ultraviolet light, and oxidation. In the body, pyridoxine is converted to the coenzyme, pyridoxal phosphate, that is involved in metabolic transformations of amino acids.

Important features of pyridoxine deficiency involve the skin, blood, and nervous system. Seborrhea-like skin lesions around the eyes, nose, and mouth accompanied by glossitis and stomatitis can be seen in vitamin B_6 deficiency. Convulsive seizures can also occur as a the result of lowered concentration of the inhibitory neurotransmitter gamma-amino butyric acid. The synthesis of this transmitter uses a pyridoxal phosphate-requiring enzyme. Changes in erythropoiesis (formation of red blood cells) caused by B_6 deficiency can cause anemia.

Isoniazid, a drug used to treat tuberculosis, inhibits the formation of the coenzyme form of pyridoxine. Therefore, vitamin B_6 is given prophylactically to patients receiving isoniazid and also to patients who have taken an overdose of the drug.

Biotin

Organ meats, egg yolk, milk, fish, and nuts are rich sources of biotin. Small amounts of biotin are also probably produced by the intestinal microflora. In the body, biotin plays an important role in both carbohydrate and fat metabolism, and it helps in excreting the waste products of protein metabolism.

Biotin is widely distributed in foods so that a deficiency state rarely exists. However, individuals consuming large amounts of raw egg white that contains avidin, a biotin-binding glycoprotein, can develop a

biotin deficiency. Signs and symptoms of biotin deficiency include dermatitis, atrophic glossitis, hyperesthesia, muscle pain, lassitude, anorexia, slight anemia, and cardiac changes. The seborrheic dermatitis of infants under 6 months of age can be due to biotin deficiency.

Folic acid

Virtually all food sources are rich in folates, especially fresh green vegetables, liver, yeast, and some fruits. However, protracted cooking can destroy up to 90% of the folate. In most foods, folic acid is combined with from one to five additional glutamic acid residues. In the body, these compounds are metabolized into a series of active coenzymes.

The specific role of the folic acid coenzymes is to transport carbon fragments from one compound to another during amino acid metabolism and nucleic acid synthesis. Thus, folic acid deficiency leads to impaired cell division and protein synthesis. Since tissues with the greatest rate of cell turnover show the most dramatic changes, the hematopoietic system that is responsible for red blood cell formation is especially sensitive to folic acid deficiency. Clinically, the earliest sign of such a deficiency is a megaloblastic anemia, in which problems with DNA synthesis cause the formation of macrocytic red blood cells.

Perhaps the most common cause of folate deficiency is acute or chronic alcoholism. Folate deficiency is also a common complication of diseases of the small intestine.

Vitamin B_{12} (Cobalamin)

Vitamin B_{12} is found in foods of animal origin such as meat, especially liver and kidney; none is present in plants. Therefore, it is particularly important for those on strictly vegetarian diets to take vitamin B_{12} supplements. In the body, cobalamin is converted to the coenzymes, methylcobalamin and 5-deoxyadenosylcobalamin. They interact with the coenzymes formed from folate in the normal synthesis of DNA and in the production of red blood cells. Vitamin B_{12} is also involved in the production of the myelin sheaths of the nerves.

The development of vitamin B_{12} deficiency during adult life is not typically the result of a dietary deficiency; rather it usually reflects a defect in gastrointestinal absorption. The intrinsic factor that is produced by gastric cells is necessary for the absorption of vitamin B_{12} from the small intestine, and loss of the intrinsic factor can cause

classic pernicious anemia. For these patients, it is necessary to inject B_{12} parenterally because it cannot be absorbed from the diet or oral supplements.

A deficiency of vitamin B_{12} can result in anemic symptoms similar to those seen in folate deficiency. It can also cause irreversible demyelination of the spinal cord.

Vitamin C (Ascorbic acid)

Vitamin C is found in fresh fruits and vegetables; fresh orange and lemon juices are outstanding sources. Vitamin C is readily destroyed by heat, oxidation, and alkali, therefore food processing can significantly reduce its level. In the body, vitamin C is not excreted by the kidney until the tissues are saturated and the concentration in the blood exceeds a preset value. The intake of vitamin C sufficient to saturate the body is about 60 to 100 mg per day. It has been suggested that several g/day of ascorbic acid are needed to maintain optimum health and maximum defense against infections, but this recommendation is controversial.

A major function of vitamin C is to aid in the formation of collagen. It is also necessary for the utilization of folic acid (one of the B vitamins), drug metabolism in the liver, and the conversion of dopamine to the neurotransmitter norepinephrine. By reducing non-heme ferric iron to the ferrous state in the stomach, vitamin C promotes intestinal absorption of iron; infant foods and adult iron supplements are often fortified with vitamin C to enhance the absorption of iron. Ascorbic acid also acts as an antioxidant by quenching free radicals, and it protects thiamine, riboflavin, folic acid, pantothenic acid, and vitamins A and E from oxidation. Vitamin C probably also has a protective or metabolic function in the eye; it is found in high concentrations in the lens and aqueous.

Vitamin C deficiency can result from infrequent dietary consumption, smoking, stress or prolonged use of antibiotics. Deficiency can produce scurvy in which there is defect in collagen synthesis causing slow wound healing, defects in tooth formation, and the rupture of capillaries leading to numerous petechiae that can coalescence to form ecchymoses.

Megadoses of vitamin C can cause the formation of kidney stones, loose bowels, skin rashes, and rebound scurvy when individuals who are consuming large quantities of vitamin C suddenly discontinue its use.

Vitamin D

Vitamin D is the name given to a group of substances including cholecalciferol and calciferol. Cholecalciferol is found in animal products, particularly fish liver oils; it can also be produced in the skin through photo-oxidation of a derivative of cholesterol. To become metabolically active, cholecalciferol is converted to calcifediol in the liver, and then further converted to calcitriol in the kidney. In the body, vitamin D regulates calcium homeostasis by enhancing the intestinal absorption of calcium, regulating calcium and phosphate release from bone, and modulating their excretion by the kidney. These processes serve to maintain plasma calcium and phosphate concentrations at levels that are essential for normal neuromuscular activity and bone mineralization.

Vitamin D deficiency is characterized by inadequate mineralization of bone. In children, the result is rickets in which there is a failure to mineralize the growing portions of the bones leading to bowlegs, knock-knees, and/or enlarged joints. In adults, vitamin D deficiency results in osteomalacia characterized by a generalized decrease in bone density.

Vitamin D is excreted from the body at a slow rate. Therefore, if an excessive amount of the vitamin is ingested, toxicity can result. Toxicity causes weakness, fatigue, lassitude, headache, gastrointestinal problems, changes in the blood pressure, and deposition of calcium in soft tissue leading to heart, kidney, and vessel damage.

Vitamin E (Alpha-Tocopherol)

Vitamin E is found in animal or plant fats and oils; wheat germ is a popular source of this vitamin. Although at least eight naturally occurring tocopherols are biological active, the most active is alpha-tocopherol which is found in most supplements. In the body, the basic function of vitamin E is to act as an antioxidant by preventing or slowing oxidation of unsaturated fatty acids in cell membranes by peroxyl free radicals. Vitamin E has been used an antioxidant in premature infants exposed to high concentrations of oxygen to reduce the incidence and severity of retinopathy of prematurity.[19]

Vitamin E deficiency can cause neurological symptoms such as hyporeflexia, gait disturbances, and ophthalmoplegia. This deficiency can also cause a pigmentary retinopathy that results in visual impairment.[20] Vitamin E is relatively non-toxic in humans; the results of consuming excessive quantities of this vitamin are not well known.

Vitamin K

Vitamin K is the name for a group of related compounds all of which are lipid soluble. This vitamin is present in green vegetables and is also produced by the bacterial flora of the intestine. Under normal circumstances, humans have little difficulty maintaining an adequate supply of vitamin K. In the body, vitamin K is required for the synthesis of prothrombin, proconvertin, plasma thromboplastin component, and the Stuart factor, all of which are required for blood clotting.

The chief clinical manifestation of vitamin K deficiency is an increased tendency to bleed. Ecchymoses, epistaxis, hematuria, gastrointestinal bleeding, and postoperative hemorrhage are seen with low vitamin K levels, and intracranial hemorrhages can occur. Vitamin K deficiency can result from prolonged antibiotic therapy that kills some of the bacteria in the intestinal lumen. Since vitamin K is fat-soluble, a deficiency can also result from the absence of bile or from biliary obstruction that affects the absorption of fat.

Calcium

A great variety of foods contain calcium with dairy products being a chief source of this nutrient. Approximately 99% of calcium in the body is joined with phosphate in the bones and teeth. The remaining calcium is essential for nerve, muscle, and cardiac function, as well as maintenance of membrane integrity, and coagulation of the blood. Calcium also mediates the intracellular actions of many hormones. Because of these various roles, calcium must be available to the appropriate tissues in the proper concentrations. This is accomplished by a control system, involving parathyroid hormone, calcitonin, and vitamin D, that keeps the plasma concentration of calcium regulated within narrow limits.

The growth of bone requires a positive calcium balance (more calcium is taken into the body than is lost) until peak bone mass is reached by about 20 years of age. More minerals are added to the bones during the third decade, and then bone mass begins to decline during the

fifth decade with an acceleration about the time of menopause in women and ten years later in men. The decrease in bone mass (osteoporosis) results in reduced bone strength and an increase risk of fractures. The risk is less for people who have developed greater bone mass earlier in life, and this seems to be related to calcium intake. Thus, the nutritional approach to reduce the risk of osteoporosis in later life is to take sufficient quantities of calcium (1,200 mg daily) through age 24 years to permit full bone development. Supplementation might be required to achieve this goal in some persons.

In post-menopausal women, the rate of decline in bone mineral is strongly dependent on estrogen levels. Estrogen replacement slows the rate of bone loss, and it has been suggested that estrogen plus calcium supplementation is the best treatment to reduce bone loss in these women.[21]

There are many ways, in addition to inadequate dietary intake, that calcium deficiency can occur. These include deficient intake of vitamin D, hypoparathyroidism, or renal insufficiency that affects vitamin D metabolism. The prominent clinical findings of calcium deficiency (hypocalcemia) include tetany, paresthesias, increased neuromuscular excitability, laryngospasm, muscle cramps, and convulsions. Hypocalcemia can also be associated with the development of lens opacities.[22]

Ingestion of large quantities of calcium is unlikely to cause toxicity, but hyperparathyroidism or vitamin D excess are classically accompanied by significantly increased calcium levels (hypercalcemia). Hypercalcemia from any etiology can cause kidney lesions, and painful bone cysts, osteoporosis, and fractures can occur if the hypercalcemia is due to hyperparathyroidism.

Chromium

Chromium is found in yeast, liver, beef, whole grains, and vegetables. Different forms of chromium with different bioavailabilities are found in these foods with the form in yeast, liver, cheese and wheat germ being the most available. In the body, chromium, along with niacin and amino acids, is a part of the glucose tolerance factor that acts with insulin to enhance glucose entry into cells.

In the United States, many people have a chromium deficiency because of relatively low soil concentrations of this mineral and the heavy processing that most foods undergo. Deficiencies of chromium can lead to impairment of glucose tolerance, and, in severe cases, a diabetes-like syndrome can result.

Copper

Organ meats, especially liver, seafoods, nuts, and seeds are dietary sources of copper. In the body, copper is an essential part of several proteins and enzymes some of which are essential for the proper utilization of iron. Superoxide dismutase is a copper-containing enzyme that acts as an antioxidant to protect the body against free radical damage.

Copper deficiency is extremely rare because the amount present in food is more than adequate to meet the body's needs. However, copper deficiency anemia has been described in individuals with intestinal bypass surgery, those on parenteral nutrition, and in malnourished infants. Copper and zinc compete for intestinal absorption and so copper deficiency could also be found in patients ingesting excessive amounts of zinc.

Iodine

Dietary sources of iodine include drinking water and vegetables, but both sources can vary in iodine content according to the mineral content of the water and the soil in which the vegetables are grown. For this reason, iodine is commonly added as a supplement to table salt. In the body, a high proportion of the iodine (70-80%) is concentrated in the thyroid gland, where it is involved in the production of the hormones thyroxine and triiodothyronine that regulate metabolism.

Dietary deficiency of iodine results in a hyperplasia of the thyroid gland known as goiter. The endemic occurrence of goiter can be caused by low amounts of iodine found in the soil and water.

Iron

Iron is present in a variety of foods of including liver, egg yolk, vegetables, and legumes. It is also found as a supplement in many processed foods. In the body, iron is used in the production of the heme portion of hemoglobin and myoglobin. It is also needed for the production

of non-heme proteins and other intracellular molecules called cytochromes that are involved in metabolism.

Iron deficiency can cause anemia characterized by small red blood cells with low hemoglobin concentration. It can also cause central nervous system transmission problems.[23] In children, iron deficiency anemia has been associated with apathy, short attention span, irritability, and reduced ability to learn.[24] Iron content in the body is regulated mainly through changes in the amount of iron absorbed by the intestinal mucosa. The amount absorbed is influenced by a variety of dietary factors. The most well-defined enhancer of iron absorption in the intestine is vitamin C, so commercial iron supplements often include this vitamin. On the other hand, calcium, phosphate, phytates, bran, polyphenols in tea, and antacids can decrease iron absorption. Menstruating women need more dietary iron because of the monthly blood loss.

Magnesium

Plants like potatoes, whole grain cereals, and green vegetables are good sources of magnesium. In the body, about 60% of the magnesium is bound with phosphates in the bones. Most of remaining magnesium is found in muscles and soft tissues where it is an essential cofactor of the enzymes involved metabolism. Magnesium also plays an important role in neuro-chemical transmission and muscular excitability.

Magnesium deficiency has not been reported in people consuming normal diets. The most prominent signs of magnesium deficiency seen with malabsorption or renal problems include nausea, muscle weakness, irritability, and mental derangement. High levels of calcium tend to aggravate the effects of low levels of magnesium, probably because calcium interferes with magnesium-requiring enzymes. Excessive concentrations of magnesium in the body, usually as a result of renal insufficiency, can reduce the heart rate and cause cardiac or respiratory arrest.

Manganese

Whole grains and cereal products are the richest dietary sources of manganese, with fruits and vegetables also providing this mineral. In the body, manganese is essential for the production of certain metalloenzymes, including some with antioxidant properties.

Manganese deficiency has never been observed in non-institutionalized individuals because of the abundant supply in edible plants. Signs of deficiency in animals include poor reproductive performance, growth retardation, congenital malformations of offspring, abnormal formation of bone and cartilage, and impaired glucose tolerance.

Phosphorus

Phosphorus is present in nearly all foods; major sources include milk, meat, poultry, fish, and cereal grains. Additional phosphorous is supplied from food additives in processed foods. In the body, 85% of the phosphorous is found combined with calcium in the bones. Phosphorous, in the form of phosphate, is found in organic esters (e.g., ATP) that are important for the transfer and storage of energy within cells. Phosphate also modifies calcium concentrations in the tissues and buffers the intracellular fluid.

Because almost all foods contain phosphorus, deficiencies do not typically occur in normal individuals. However, the transport of phosphorous, in the form of phosphate, from the intestinal tract can be interfered with by large quantities of calcium or aluminum. This is because these minerals form insoluble phosphates that cannot be absorbed. A few individuals taking aluminum hydroxide antacids for prolong periods have developed a phosphorous deficiency resulting in bone loss, weakness, anorexia, malaise, and pain.

Potassium

Foods rich in potassium include fruits, many vegetables, and fresh meats. In the body, potassium is found predominately within the cells. The small amount of extracellular potassium is of great physiological importance in the transmission of nerve impulses, skeletal muscle contractility, and maintaining normal blood pressure.

Under normal circumstances, potassium deficiency does not occur, but it can be caused by excessive loss due to the use of diuretic drugs for the treatment of hypertension. Deficiency symptoms include weakness, anorexia, nausea, listlessness, drowsiness, and irrational behavior. Severe potassium deficiency (hypokalemia) can result in fatal cardiac arrhythmias.

Selenium

Seafood, kidney, and liver are consistently good sources of selenium, whereas grains and other seeds are more variable sources that depend on the selenium content of the soils in which they are grown. Direct evidence for a selenium requirement in the body was lacking until 1979 when an association between low selenium levels and Keshan disease, a cardiomyopathy, was reported.[25]

In the body, selenium is essential for the antioxidant enzyme glutathione peroxidase which helps to breakdown peroxide free radicals. Other suggested uses for this mineral include the treatment or prevention of high blood pressure, stokes, heart attacks, cancer and arthritis.

Sodium

Most foods contain small amounts of sodium, but much of the dietary intake of sodium results from the salt that is added to food while cooking, during processing, or at the table. In the body, sodium is the primary regulator of extracellular fluid volume, osmolarity, acid-base balance, and the membrane potentials of cells. Sodium levels are maintained over a wide range of dietary intake levels, primarily by the action of the hormone aldosterone on the kidney.

Dietary deficiency of sodium does not occur in normal diets, and even relatively heavy sweating does not normally create the need for salt supplements. Acute, excessive salt intake can lead to an increase of water in the extracellular spaces that can produce edema and hypertension. Since the kidney can easily excrete excess sodium, such an acute intake is not of concern as long as sufficient water is ingested. However, chronic over-consumption of sodium by sensitive individuals has been related to the development of systemic hypertension.[26]

Zinc

Zinc is found in most foods with meat, liver, eggs and seafood being good sources; whole grain products contain zinc in a less available form probably because of the associated fiber. In the body, zinc is involved in most major metabolic pathways including those involved in gene expression. It is also associated with two enzymes that are part of the antioxidant system: superoxide dismutase which acts on the superoxide radical, and catalase which acts on hydrogen peroxide.

A zinc deficiency can mimic a retinol (vitamin A) deficiency because zinc is required to convert retinol (vitamin A) to retinal. Without zinc, less visual pigment is made and this can result in night blindness or reduced color sensitivity.

Although zinc is readily available in the diet, sub-marginal zinc nutrition has been reported in apparently healthy American children.[27] These children had sub-optimal growth, poor appetite, and impaired taste acuity. The signs and symptoms of frank zinc deficiency include loss of appetite, growth retardation, skin changes, and immunological abnormalities. Pronounced zinc deficiency in males can also result in hypogonadism and dwarfism. Zinc deficiency during pregnancy can lead to developmental disorders in the offspring.

EFFECTS OF VITAMIN AND MINERAL NUTRITURE ON VISUAL FUNCTION

Because vitamin and mineral nutriture is so important in all aspects of physiology, it should not be surprising that it has a significant effect on visual function. It should also not be surprising that the confusion, uncertainty, and change associated with the entire topic of nutrition would be found in the literature on vision. On one extreme, it has been suggested that almost every vision or visually related problem from myopia to dyslexia is associated with sub-optimum vitamin and mineral nutriture. On the other extreme, some doctors believe that nutritional problems are important only in frank pathological conditions such as keratomalacia, or for the management of free radical diseases.[4-6,9,28] The truth probably lies somewhere between these positions, so the problem for the optometrist is to know which visual conditions are nutritionally based and which are not. This problem is compounded by the fact that the body of knowledge upon which researchers, government regulators, nutritionists, and supplement makers base their nutritional claims and recommendations keeps changing.

Health care providers have reacted to these changes in different ways. Some have decided that until more information is available, it is appropriate to give supplements to all patients. Others feel that since little evidence relates visual performance to nutriture, recommending supplementation is an unnecessary expense. They might also feel that recommending an over-the-counter supplement to be purchased in a

grocery or discount store is not in keeping with their professional image. Still another group of health care providers have learned enough about vitamin and mineral nutriture to recommend a trial with appropriate and specific supplements for those patients whose signs and symptoms suggest a nutritional problem.

To help in identifying patients who have visual problems that might respond to supplementation, the literature relating vitamin and mineral nutriture to visual performance has been summarized below. The summary is divided into sections dealing with neural transmitters, accommodation, eye movements, nystagmus, refractive conditions, dark adaptation, acuity, and perceptual/cognitive functions. In each of these sections, major references found in MEDLINE® and PsycLIT® searches covering at least the past 5 years have been reviewed. These databases include articles in peer-reviewed, scientific journals, but exclude many journals which contain anecdotal and small group studies. It is difficult to put the papers in these non-peer-reviewed journals into perspective; should a doctor elect to treat a patient on the basis of a single case study, or on the basis of an experiment without adequate controls? It will no doubt take many years of careful scientific study to separate the valid from the invalid claims in this area. Until this happens, the decision about whether to prescribe supplements for the enhancement of visual function in otherwise normal patients will be a difficult one.

Because the neural transmitters are vitally important in all aspects of visual function and perception, they will be reviewed first.

Neural Transmitters

Each of the eight common neural transmitters is derived from the products of nutrient metabolism. For example, the transmitter acetylcholine is derived from choline that is found in plant and animal foods such as egg yolks and wheat germ. Acetylcholine is used by parasympathetic postganglionic neurons that are involved in cardiovascular, glandular, and digestive functions. In the visual system, activation of the parasympathetic nervous system produces accommodation, pupillary constriction, and a tendency for the eyes to converge because of the link between accommodation and convergence. Acetylcholine is also used by motor neurons including those serving the extra-ocular muscles.

Theoretically, a patient with a choline deficiency resulting in insufficient acetylcholine production would have many problems including larger than normal pupils, decreased accommodative and/or convergence ability, an increased accommodative lag, and eye movement problems. Although this possibility is suggestive, no major studies relating choline supplementation to enhancement of these visual functions were found.

Other synapses in the nervous system use catecholamine transmitters, including dopamine, norepinephrine, and epinephrine, that are produced from the amino acid tyrosine. Peripherally, norepinephrine is used as a transmitter in postganglionic neurons of the sympathetic nervous system. Activation of this system causes pupillary dilation, negative accommodation, and a tendency for the eyes to diverge because of the link between accommodation and convergence. Reduced sympathetic transmitter availability, possibly caused by a problem with tyrosine metabolism, could result in pupillary constriction, over-accommodation, and a tendency for over-convergence. Again, however, no studies have demonstrated that these problems could be managed with tyrosine supplementation.

Serotonin is a transmitter involved in many aspects of brain function. For example, it seems to be involved in the regulation of carbohydrate intake, and may play a role in carbohydrate craving obesity and seasonal affective disorder (SAD).[29] SAD patients experience depression as a result of reduced light stimulation during the winter months, and some studies have suggested that the retinas of SAD patients become less responsive to light during the winter.[30] Therapy for SAD involves increasing the light delivered to the patient's visual system by the use of supplemental illumination. Serotonin's precursor, tryptophan, is usually not in short supply in the diet, but one study has shown that a deficiency can affect visual perception.[31]

Accommodation

Normal accommodative function requires that several components of the visual system work in a coordinated manner, and any problems that affect these components would affect accommodation. Unfortunately, few studies have shown specific links between accommodative function and vitamin or mineral nutriture. An exception is a Japanese study which

demonstrated that vitamin B_{12} supplementation improved accommodative function following a sustained near-point task.[32]

It also has been shown that systemic poisons such as alcohol can affect accommodation. There is a correlation between increasing blood alcohol level and receding near-point of accommodation,[33] and the latency and duration of accommodative responses are affected by alcohol use.[34]

Eye Movements

Like accommodation, eye movements can be affected by alcohol. Effects of acute intoxication include an exaggerated end-point nystagmus and deterioration of smooth pursuit movements into a series of small saccades. A nystagmus detectable with the eyes horizontally deviated 45 degrees from the primary position also occurs when blood alcohol levels reach about 0.10 %.[35] Detection of these abnormal eye movements is used by traffic officers in field sobriety tests administered to suspected drunk drivers.

Other effects of alcohol on the oculo-motor system include an inverse relationship between blood alcohol level and near-point of convergence.[33] Increased exophoria and decreased convergence have also been reported during alcohol intoxication.[36]

Toxic heavy metals can affect eye movements. For example, sub-toxic levels of lead in the blood of workers chronically exposed to this environmental hazard have been linked to decreased accuracy during visual pursuit tasks.[37]

Nystagmus

Many nutritional and metabolic problems can produce nystagmus. For example, vitamin B_{12} deficiency can cause spinal and peripheral neuropathies affecting the nerves controlling eye movements,[38] and this can produce a downbeat nystagmus,[39] and a paralysis or paresis of upward gaze.[40]

Nystagmus can be due to demyelination secondary to a thiamine deficiency that will improve almost immediately with supplementation. For these patients, supplementation with magnesium should also be given concurrently with the thiamine to achieve best results.[41] The nystagmus found in Wernike's encephalopathy (bilateral, variable jerky nystagmus with horizontal and vertical components that are exaggerated on extreme gaze) can be seen in some adult alcoholic patients with thiamine

deficiencies.[42] It is also found in malnourished infants.[43]

Deficiencies of other vitamins and minerals can cause nystagmus. In some cases, a low magnesium level has been shown to be the primary cause of downbeat nystagmus,[41] and vitamin E deficiency can result in nystagmus accompanied by reduced speed of abduction.[44]

Refractive Conditions

Many researchers have sought a nutritional cause for the development of refractive errors. For example, it has been speculated that myopia might be linked to a calcium or vitamin C deficiency. Although the idea that poor nutriture could make the sclera weaker, thereby allowing intra-ocular pressure to elongate the globe is interesting, it has not been substantiated in any major studies.

Another theory linking nutriture to myopia development suggests that many nutrients interact to affect the regulation of both accommodation and intra-ocular pressure.[45] According to this theory, depression of the chromium/vanadium ratio in the tissue, reduced dietary folic acid intake, an excessively high or low intake of ascorbic acid, excessive dietary phosphorus, and a high ratio of sucrose to complex carbohydrates intake all are risk factors for myopia development. While intriguing, this theory has not been substantiated and has not gained widespread acceptance.

Zinc, vitamins A and E, and protein nutriture have also been suggested as being involved in development of refractive errors. Several studies have shown that children deprived of protein become more myopic than children with normal nutrition.[46,47]

Dark Adaptation

The photopigments in both rods and cones are based on the vitamin A derivative, retinal. In rods, retinal combines with an opsin to make rhodopsin, and in cones it makes the three types of cone pigments. Patients who experience a vitamin A deficiency often complain about the inability to see well at night because it is hard for them to regenerate their rhodopsin with an inadequate supply of vitamin A. This condition can be treated with vitamin A supplementation,[48,49] but it must be kept in mind that vitamin A in large quantities is toxic.

A zinc deficiency can also cause reduced ability to see well at night.[50-52] This is because the zinc-mediated process which releases

vitamin A from liver storage can not operate properly when there is a zinc deficiency. Additionally, the conversion of retinol to retinal for photopigment synthesis is mediated by alcohol dehydrogenase (ADH) which is a zinc metalloenzyme.[52]

Because alcohol competes with retinol for ADH, less retinal is produced during alcohol intoxication and this can lead to reduced rhodopsin formation.[53] In alcoholics, this difficulty, combined with poor vitamin A absorption, liver problems, and increased zinc excretion can make dark adaptation a significant problem.[52]

Vitamin E deficiency can also cause difficulties in dark adaptation. Patients with fat malabsorption problems such as abetalipoproteinemia and cystic fibrosis often experience this problem.[20,54]

Acuity

Vitamin A deficiency, common in patients with chronic fat malabsorption, can produce a reduction in visual acuity.[47,55,56] However, patients with excessive vitamin A levels (hypervitaminosis A) can also present with a loss of visual acuity,[47,57] so care must be taken before recommending supplementation. Hypervitaminosis A is unlikely in undeveloped countries, but it can occur where foods are vitamin enriched and excessive supplementation is used. It can also occur in cultures where the livers of animals are consumed raw or in excessive quantities.

Riboflavin (vitamin B_2) deficiencies can result in reduced visual acuity along with the other problems mentioned previously. Typically, riboflavin supplementation causes prompt return of normal acuity in deficient patients.[55] Vitamin E deficiency has also been linked with reduced visual acuity;[20,58,59] and a deficiency of docosahexaenoic acid (omega-3 fatty acid), which is the major polyunsaturated fatty acid in the photoreceptor membranes, can create a similar acuity problem.[60]

It is uncertain whether acute alcohol intoxication affects acuity directly,[33] but chronic alcoholics can present with an amblyopia characterized by centrocecal scotomas. Visual acuity losses reported in these patients can range from 20/30 to 20/200. Because chronic alcoholism is associated with vitamin deficiencies, an adequate diet plus thiamine, folic acid, and vitamin B_{12} supplementation is typically recommended.[61]

Similar to alcohol, excessive tobacco use can produce a toxic amblyopia that many believe is caused by an increased level of cyanide in the blood.[62] However, this condition also responds to vitamin supplementation therapy.[63]

Finally, blood sugar regulation problems, such as hypoglycemia, can cause transiently decreased visual acuity. Hypoglycemic patients can also demonstrate convergence and accommodative insufficiencies.[64]

Perceptual/Cognitive Functions

Deficiencies in several vitamins and minerals can influence perceptual/cognitive functions such as hand-eye coordination, learning, and memory. For example, deficits in vitamins B_1, B_6, and B_{12} levels can affect fine hand-eye coordination,[65,66] and vitamin B_{12} levels in geriatric patients were found to be correlated to visual memory and other cognitive abilities.[67]

Iron must be present in sufficient quantities to insure good perceptual function. Anemic subjects receiving iron supplementation have shown significant increases in academic and cognitive functions,[68] as well as increases in visual attention and concept acquisition skills.[24]

Some learning disabled and retarded children have been found to have low serum zinc levels which might be related to their learning problems.[69] This theory is supported by the finding that mild zinc deficiencies in experimental animals increase the time required to learn a visual discrimination task.[70] It has been suggested that the effects of reduced zinc levels on learning could be mediated by a reduction in the RNA polymerase activity necessary for memory formation.[69]

Deficiencies in other minerals can also affect memory formation. For example, the iodine deficiencies occasionally encountered in Europe have been shown to impair cognitive function.[71]

Large doses of vitamin C can create sedative-like effects, and this can produce a detrimental effect on reaction times.[72] When subjects were given 1 to 2 grams of vitamin C, response to a light stimulus was significantly impaired in a dose-dependent manner. This suggests that although vitamin C plays an important role in the body, excessive amounts can have unwanted side-effects.

Patients with chronic dopamine deficiency associated with phenylketonuria can have decreased reaction times, and can have problems in controlling their visual attention.[73]

Changes in a variety of perceptual/cognitive functions, such as the ability to hold sustained attention on a visual task, can be associated with lead intoxication. In a study of 59 people exposed to lead in the work place (only one of whom had a "toxic" lead level), sustained visual tracking ability was significantly decreased.[37] Even relatively low lead levels have been shown to cause degraded hand/eye coordination on pursuit motor tasks;[74] increases in motor tremors, probably due to slowing of sensory and motor nerve conduction velocities;[37,75,76] decreased critical flicker fusion frequencies; increased reaction times; and impairment of both sensory and short-term memory.[37]

In addition to lead, other substances including cadmium, aluminium, and organic solvents can cause perceptual/cognitive deficits. Cadmium has been implicated in some cases of learning and/or developmental deficits involving decreased visual-perceptual development in children.[77] A correlation has also been found between increased lead and cadmium levels and decreased performance on the Bender Visual-Motor Gestalt Test.[78]

Organic solvents, such as toluene, can produce impairments of visuo-motor ability and manual dexterity.[79] Memory tasks can be impaired in workers chronically exposed to a mixture of organic solvents,[80] and difficulty controlling visual attention has been found after chronic exposure to these chemicals.[79]

High serum levels of aluminum have been linked to long-term (but not short-term) memory difficulties.[81] Decreased critical flicker fusion frequencies have been also found along with problems on visuo-motor tasks.[81]

CONCLUSIONS

If the state of knowledge regarding general nutrition is confusing for doctors and patients, the state of knowledge relating the use of vitamin and mineral supplements to the enhancement of visual function is perplexing. The main-stream, scientific literature provides little solid support for those who would like to use these supplements to increase visual function in patients without frank deficiencies.

Why is there such a dearth of information on the use of vitamins and minerals to enhance vision, especially when many functionally-oriented doctors frequently recommend supplements? Part of the reason is that much of the existing information is unpublished, anecdotal, and/or in literature that cannot be retrieved by electronic means. Does the existing, peer-reviewed, scientific literature support the use of vitamin and mineral supplementation for otherwise healthy patients who have accommodative, convergence, and/or learning problems? Probably not. But, on the other hand, is it reasonable to conduct a short-term trial with appropriate supplements for patients who have vision performance problems? The answer to this question is probably yes.

What would be required to conclusively prove that supplementation could help normal patients achieve a maximum level of visual performance? How can research be designed to investigate this issue? The answers to these questions are very difficult to determine. Some doctors commonly prescribe vitamin and mineral supplements along with vision therapy (VT), but how can they separate the effects of the vitamins and minerals from the VT? And even if they prescribe only vitamins and minerals, can they be sure that the supplements were actually absorbed and that the patient had the necessary metabolic machinery to make use of the vitamins and minerals?

At the university level, research can be done on the effects of supplementation, but this requires large numbers of subjects with similar problems, careful blood and physiological monitoring of vitamin and mineral utilization in the body, and assessment of changes in visual function. Such a project would require multiple sites along with many thousands of dollars to complete. For these reasons, it is unlikely that scientific validation of vitamin and mineral supplementation for the enhancement of visual function in normal subjects will be available in the near future. This means that, for now, doctors recommending nutritional supplementation for the enhancement of visual performance must do so on the basis of suggestive, but inconclusive, data.

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Figure Caption:

Figure 1. This figure has been reprinted (with slight modifications) with permission from Recommended Dietary Allowances, 10th Edition.[8]

FOOD AND NUTRITION BOARD, NATIONAL ACADEMY OF SCIENCES—NATIONAL RESEARCH COUNCIL

RECOMMENDED DIETARY ALLOWANCES,[a] Revised 1989

Designed for the maintenance of good nutrition of practically all healthy people in the United States

Category	Age (years) or Condition	Weight[b] (kg)	Weight[b] (lb)	Height[b] (cm)	Height[b] (in)	Protein (g)	Fat-Soluble Vitamins: Vitamin A (μg RE)[c]	Vitamin D (μg)[d]	Vitamin E (mg α-TE)[e]	Vitamin K (μg)	Water-Soluble Vitamins: Vitamin C (mg)	Thiamin (mg)	Riboflavin (mg)	Niacin (mg NE)[f]	Vitamin B_6 (mg)	Folate (μg)	Vitamin B_{12} (μg)	Minerals: Calcium (mg)	Phosphorus (mg)	Magnesium (mg)	Iron (mg)	Zinc (mg)	Iodine (μg)	Selenium (μg)
Infants	0.0–0.5	6	13	60	24	13	375	7.5	3	5	30	0.3	0.4	5	0.3	25	0.3	400	300	40	6	5	40	10
	0.5–1.0	9	20	71	28	14	375	10	4	10	35	0.4	0.5	6	0.6	35	0.5	600	500	60	10	5	50	15
Children	1–3	13	29	90	35	16	400	10	6	15	40	0.7	0.8	9	1.0	50	0.7	800	800	80	10	10	70	20
	4–6	20	44	112	44	24	500	10	7	20	45	0.9	1.1	12	1.1	75	1.0	800	800	120	10	10	90	20
	7–10	28	62	132	52	28	700	10	7	30	45	1.0	1.2	13	1.4	100	1.4	800	800	170	10	10	120	30
Males	11–14	45	99	157	62	45	1,000	10	10	45	50	1.3	1.5	17	1.7	150	2.0	1,200	1,200	270	12	15	150	40
	15–18	66	145	176	69	59	1,000	10	10	65	60	1.5	1.8	20	2.0	200	2.0	1,200	1,200	400	12	15	150	50
	19–24	72	160	177	70	58	1,000	10	10	70	60	1.5	1.7	19	2.0	200	2.0	1,200	1,200	350	10	15	150	70
	25–50	79	174	176	70	63	1,000	5	10	80	60	1.5	1.7	19	2.0	200	2.0	800	800	350	10	15	150	70
	51+	77	170	173	68	63	1,000	5	10	80	60	1.2	1.4	15	2.0	200	2.0	800	800	350	10	15	150	70
Females	11–14	46	101	157	62	46	800	10	8	45	50	1.1	1.3	15	1.4	150	2.0	1,200	1,200	280	15	12	150	45
	15–18	55	120	163	64	44	800	10	8	55	60	1.1	1.3	15	1.5	180	2.0	1,200	1,200	300	15	12	150	50
	19–24	58	128	164	65	46	800	10	8	60	60	1.1	1.3	15	1.6	180	2.0	1,200	1,200	280	15	12	150	55
	25–50	63	138	163	64	50	800	5	8	65	60	1.1	1.3	15	1.6	180	2.0	800	800	280	15	12	150	55
	51+	65	143	160	63	50	800	5	8	65	60	1.0	1.2	13	1.6	180	2.0	800	800	280	10	12	150	55
Pregnant						60	800	10	10	65	70	1.5	1.6	17	2.2	400	2.2	1,200	1,200	300	30	15	175	65
Lactating	1st 6 months					65	1,300	10	12	65	95	1.6	1.8	20	2.1	280	2.6	1,200	1,200	355	15	19	200	75
	2nd 6 months					62	1,200	10	11	65	90	1.6	1.7	20	2.1	260	2.6	1,200	1,200	340	15	16	200	75

[a] The allowances, expressed as average daily intakes over time, are intended to provide for individual variations among most normal persons as they live in the United States under usual environmental stresses. Diets should be based on a variety of common foods in order to provide other nutrients for which human requirements have been less well defined.

[b] Weights and heights of Reference Adults are actual medians for the U.S. population of the designated age, as reported by NHANES II. The use of these figures does not imply that the height-to-weight ratios are ideal.

[c] Retinol equivalents. 1 retinol equivalent = 1 μg retinol or 6 μg β-carotene.

[d] As cholecalciferol. 10 μg cholecalciferol = 400 IU of vitamin D.

[e] α-Tocopherol equivalents. 1 mg d-α tocopherol = 1 α-TE. calculation of vitamin E activity of the diet as α-tocopherol equivalents.

[f] 1 NE (niacin equivalent) is equal to 1 mg of niacin or 60 mg of dietary tryptophan.