What Do Essential Nutrients Actually *Do*?

The functions of vitamins and essential minerals are well known, and each of them plays one or more key roles in maintaining the daily functions basic to health and life itself. These functions are accomplished in every cell and every organ of the body, every minute of every day, from birth to death.

Some of these functions may ultimately provide some protection against chronic diseases such as cancer and heart disease. However, it is their more mundane but vital roles in metabolism that cause vitamins and minerals to be defined as "essential nutrients." The following is intended as a simplified reminder of the immense scope of these basic functions.

Vitamins and essential minerals are components of enzymes and cofactors the body needs to accomplish the everyday miracles of constantly keeping the heart beating, the blood flowing, the muscles flexing, the bones strong, the digestive system churning efficiently, the cells dividing, the eyes sparkling, the skin protecting our outer and inner surfaces, countless membranes controlling what goes into and out of every cell and tissue, the kidneys filtering the blood and adjusting blood pressure, the lungs drawing in life-giving oxygen and expelling other gases, the nerves snapping, and the brain cogitating.

The collective magnitude of these activities is illustrated by the fact that a large fraction of the body's total energy expenditure is devoted to maintaining these functions. This portion of the total daily energy requirement is known as the basal metabolic rate (BMR), and it accounts for 50 to 70 percent of the body's total daily energy expenditure. (Gropper, Smith, et al., 2009)

The essential nutrients are critical to the performance of these functions. An essential nutrient is a substance the body must have in order to function, but which it cannot make for itself. Therefore, the nutrient must be obtained from outside sources, namely foods. There are 13 vitamins (which by definition are essential), 15 essential minerals or electrolytes, nine essential amino acids, and a couple of essential fatty acids. Given an adequate supply of calories (from a mixture of fats, carbohydrates, and protein) and plenty of water, the body can use these essential nutrients to mix and match the various other components of foods and turn them into its own personal energy supply as well as continually creating new cells and tissues, blood and bone, muscles and brain, skin and hair. The essential nutrients in many cases are the catalysts or cofactors that make these operations possible.

The cells in the adult body are not the ones we were born with, since all of the body cells and tissues are constantly turning over—being worn out and repaired or replaced with new ones. Some tissues, like the cells lining the intestinal tract, turn over very rapidly—about every three days. The red blood cells turn over about every 120 days, and newly manufactured ones continually take the place of the old ones. Some other body cells and tissues may last for years, but even those are subject to constant repair.

Needless to say, any fault or faltering in these processes could have a direct impact on the body's ability to function. The nature of the impact will depend on which nutrients are in short supply and what tissues are affected.

B VITAMINS: THE POWERHOUSE

Many of the B vitamins are involved in energy production, every second of every day. They are coenzymes that make it possible for the body to convert carbohydrates, fats, and proteins into usable energy that can be used to run the system, much like a power plant turns fuel into usable electricity that can run household appliances. Metabolic systems such as the Krebs cycle and the electron transport chain form the basis of the body's power plant, which exists in every cell and is dependent on several of the B vitamins, especially thiamin, riboflavin, niacin, and pantothenic acid.

The energy-related B vitamins work together as a team, passing electrons, carboxyl groups, or phosphates around with lightening speed in order to produce energy exactly when and where it is needed. Each vitamin in this team has its own particular function in the process, and each must fulfill its role in order for adequate energy to be produced.

People with inadequate intakes of these B vitamins have low energy, which is apparent not only in a decreased capacity for work but also in effects on cognitive function and "nerve." In a historic 1942 article urging the enrichment of white bread with thiamin (vitamin B-1) and other B vitamins, two prominent nutrition researchers asserted that "a first result of deficiency of thiamin is loss of courage and the will to do or die." (Williams & Wilder, 1942) This assertion may have been hyperbole arising from the pressures of the war effort, but it was grounded in an appreciation of the fundamental impact of the B vitamins on a person's mood and capability, as well as physical energy.

BUILDING BLOOD AND OTHER CELLS AND TISSUES

Many of the B vitamins are involved in synthesizing the basic building blocks of the body. They are components of the "one-carbon cycle," which generates methyl groups used in the synthesis of compounds such as amino acids, proteins, enzymes, neurotransmitters, hormones, and DNA. The key B vitamins involved in manufacturing these basic components include folate (folic acid), vitamin B-12, and vitamin B-6. They are critical to the existence and function of all cells, but are especially vital in supporting fast-growing tissues such as blood cells, the cells lining the gastrointestinal tract, and the rapidly growing fetus.

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Red blood cells are made in the bone marrow, and they begin their life as large cells. Given an adequate supply of folic acid and vitamin B-12 for DNA manufacture and cell division, the large cell splits into smaller ones, which are precursors of the red blood cells (erythrocytes). If folic acid and B-12 are not sufficient to support normal DNA production and cell division, the large cell fails to split properly and remains "megaloblastic" (large). This eventually results in megaloblastic anemia, in which the red blood cells are large but are reduced in number (because they failed to split normally and evolve into normal erythrocytes) and are inefficient in performing their basic functions of delivering hemoglobin and oxygen to the tissues. (Gropper, Smith, et al., 2009; Smolin & Grosvenor, 2010)

Iron is the critical component of hemoglobin, whose function is to carry oxygen from the lungs to the heart, and then from the heart to all the tissues of the body. If iron is in short supply, then too little hemoglobin is produced, and the red cells are pale and small (microcytic). Accordingly, the anemia that eventually results from iron deficiency is called microcytic anemia. Iron is also the critical component of myoglobin, a sister compound to hemoglobin, which provides oxygen to muscle cells. (Gropper, Smith, et al., 2009; Smolin & Grosvenor, 2010)

The effects of iron deficiency can be observed long before any actual anemia develops, and those effects include reduced physical work capacity and impaired cognitive function. (Institute of Medicine, 2006)

It is difficult to fully comprehend the extent of the biosynthesis that occurs in the body—the extent to which we are the product of our own metabolic pathways. The author Annie Dillard, in her beautiful book *Pilgrim at Tinker Creek,* contemplates this phenomenon, using the nephrons of the kidney as a case in point:

> **"The Henle's loop is an attenuated oxbow or U-turn made by an incredibly tiny tube in the nephron of the kidney. The nephron in turn is a filtering structure which produces urine and reabsorbs nutrients...There is no way to describe a nephron; you might hazard into a fairly good approximation of its structure if you threw about fifteen yards of string on the floor. If half the string fell into a very narrow loop, that would be the Henle's loop...But the heart of the matter would be a very snarled clump of string... which is the glomerulus...This is the filter to end all filters...Now the point of all this is that there are a million nephrons in each human kidney. I've got two million glomeruli, two million Henle's loops, and I made them all myself, without the least effort. They're undoubtedly my finest work."** (Dillard, 1974)

CALCIUM AND VITAMIN D FOR MANY FUNCTIONS, NOT JUST BONES

Calcium and vitamin D are both needed in adequate amounts in order to facilitate the absorption of calcium from food and in order to maintain essential levels of calcium for many metabolic functions. Calcium is of course a critical component of bone. Getting generous amounts of calcium and vitamin D can help build greater bone mass during the growth years, help slow bone loss during aging, and even help prevent or delay fractures. However, building bones is only one aspect of calcium's function. Calcium is also a critical component of extracellular and intracellular fluids, and the body puts a higher priority on maintaining a steady state of calcium in extracellular and intracellular fluids than on retaining calcium in bones. In fact, the body treats the bones as a reservoir from which calcium can be withdrawn as needed to replenish the circulating supply. In a nutshell, this is why the bones are so vulnerable to low calcium intakes.

Calcium in the blood, muscle, and other tissues is essential for the contraction and dilation of blood vessels, neural transmission, and glandular secretion. Calcium is also essential for muscle contraction, and muscle contraction is vital to existence. The muscles of the heart contract and relax and contract again every second of every day, whether we are awake or asleep, reading or running, working or relaxing. The muscles of the arteries and veins react to the pumping of the heart and keep the blood flowing to the furthest reaches of the toes and fingers and back again, around and around and around. The muscles of the gastrointestinal tract actively push food through the system, permitting the body to take in the nutrients it needs and eliminate unwanted waste, hour after hour and day after day. The muscles of the diaphragm contract and relax, pulling life-giving oxygen into the lungs and expelling other gases, without ceasing.

The body strictly maintains a steady level of circulating calcium to fulfill these functions, even if that means taking calcium from bones, so it is important to get enough calcium every day to maintain the circulating level and also to maintain bone strength. Most people don't do a very good job of this, and the bones pay the price.

VITAMIN C FOR COLLAGEN: HOLDING EVERYTHING TOGETHER

The bones, of course, are not stacked one on top of the other in a precarious balance. They are firmly tied together and their muscles are firmly attached by

connective tissue—tendons and ligaments made of collagen. Collagen is a strong, smooth, white connective tissue that cushions the bones at intersections and joints so they move smoothly, that holds muscle bundles in place so they can effectively move the limbs, and that keeps the teeth firmly in place in the gums. Collagen, like bone, is made by the body from scratch, a manufacturing process which requires vitamin C.

When vitamin C is low, strong collagen will not be produced and maintained, "resulting in symptoms such as poor wound healing, the reopening of previously healed wounds, bone and joint aches, bone fractures, and improperly formed and loose teeth. Connective tissue is also important for blood vessel integrity. A vitamin C deficiency therefore causes weakened blood vessels and ruptured capillaries, which leads to symptoms such as tiny bleeds around the hair follicles, bleeding gums, and easy bruising." (Smolin & Grosvenor, 2010)

ANTIOXIDANT PROTECTION

In the course of normal metabolism, the cells and tissues are exposed to oxidation, which can be beneficial or can cause damage. Oxidation occurs when an electron is lost, and an oxidized molecule can be reduced if another nearby compound donates an electron. A substance with an unpaired electron is a "free radical." Numerous antioxidants are present in the blood and in the cells and membranes, and they can donate an electron when necessary. They are then rapidly regenerated by other antioxidants. The antioxidant defense system includes vitamin C, vitamin E, and some enzymes containing trace minerals such as selenium and zinc.

Vitamin C is a water-soluble antioxidant capable of scavenging free radicals and protecting against lipid oxidation. Vitamin E is a fat-soluble, chain-breaking antioxidant that can prevent the spread of free-radical reactions, especially in lipids. It scavenges free radicals and protects polyunsaturated fatty acids within membranes. Selenium is a component of many enzymes including glutathione peroxidase, and zinc is a component of superoxide dismutase, an enzyme that helps protect cells from free radical damage. (Institute of Medicine, 2006)

VITAMIN A FOR EYESIGHT AND OTHER FUNCTIONS

Vitamin A is essential for normal vision, gene expression, reproduction, development of the fetus, growth, and immune function. One of the earliest signs of low vitamin A status is night blindness (slow adaptation to the dark). Vitamin A activity is provided by retinol from animal sources and numerous carotenoids from plant sources. Carotenoids are the natural pigments in deeply colored fruits and vegetables, and the most common in the U.S. diet are alpha-carotene, beta-carotene, lycopene, lutein, zeaxanthin, and beta-cryptoxanthin. (Institute of Medicine, 2006)

Vitamin A is critical for the development and maintenance of healthy epithelial tissue, including the skin and the lining of internal surfaces such as the GI tract. The epithelial cells in the eye are "particularly susceptible to damage. The mucus in the eye normally provides lubrication, washes away dirt and other particles, and also contains a protein that helps destroy bacteria. When vitamin A is deficient, the lack of mucus and the buildup of keratin cause the cornea to dry and leave the eye open to infection." (Smolin & Grosvenor, 2010) This can lead to rupture of the cornea and permanent blindness. In the developing world, vitamin A deficiency is the leading cause of blindness in children under the age of five, and also increases their risk of infection and mortality.

ZINC FOR GROWTH AND IMMUNE FUNCTION

Zinc is the most abundant trace element in the cells, where is it integral to the functioning of more than 300 enzymes. (Smolin & Grosvenor, 2010) It is essential for growth and development. Impaired rate of growth in young children is often related to zinc insufficiency, and a modest level of zinc supplementation has been shown in some studies to help correct it. Zinc supplementation can contribute to healthier pregnancies and improved immune function. (Institute of Medicine, 2006)

NUTRIENT EFFECTS ON ENZYME FUNCTION AND DNA

Many of the vitamins function as cofactors for enzymes, and many of the essential minerals are integral components of the hundreds of enzymes that are functioning in the body all the time. The rates of reaction are governed by enzyme kinetics—the rate at which enzymes bind with their target compounds or their cofactors, accomplish their work, and then release the product. This rate can vary from one individual to another. Just as some people can jump high and some people can't, some people have very efficient metabolisms and others don't. Since vitamins are the cofactors that help enzymes to function, it may sometimes be possible to boost enzyme function by giving additional amounts of some vitamins.

Dr. Bruce Ames is a prominent biochemist who believes generous intakes of vitamins can "tune up" the metabolism and thus improve health or even delay aging. (Ames, 2004) According to Dr. Ames: "Americans' intake of the 40 essential micronutrients (vitamins, minerals, and other biochemicals that humans require) is commonly thought to be adequate. Classic deficiency diseases, such as scurvy, beriberi, pernicious anemia, and rickets, are rare. The evidence suggests, however, that much chronic metabolic damage occurs at levels between the level that causes acute micronutrient deficiency disease and the recommended dietary allowances (RDAs). In addition, the prevention of more subtle metabolic damage may not be addressed by current RDAs. When one input in the metabolic network is inadequate, repercussions are felt on a large number of systems and can lead to degenerative disease. This may, for example, result in an increase in DNA damage (and cancer), neuron decay (and cognitive dysfunction) or mitochondrial decay (and accelerated aging and degenerative diseases)... A tune-up of micronutrient metabolism should give a marked increase in health at little cost." (Ames, 2004)

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It is known that there are genetic mutations that affect key enzymes, and many of these mutations result in a lower rate of reaction for the enzyme. Dr. Ames continues: "About 50 human genetic diseases due to defective enzymes can be remedied or ameliorated by the administration of high doses of the vitamin component of the corresponding coenzyme, which at least partially restores enzymatic activity." The B vitamins are prominent among these coenzymes. Dr. Ames predicts that, with a better understanding of the genomics involved, "it will become possible to customize vitamin therapies to suit the genotypic, and thus more specific, needs of individuals, instead of treating the phenotype." (Ames, Elson-Schwab, et al., 2002)

Dr. Ames has proposed that, when nutrients are in short supply, they are allocated by the body to vital functions such as energy production, possibly at the expense of functions important to long-term health. This allocation is a form of triage, and it could occur in part through altering the binding affinity of an enzyme for its vitamin or mineral cofactor. "The consequences of such triage would be evident at all levels," he says. "For example, in metabolic reactions, enzymes involved in ATP synthesis would be favored over DNA-repair enzymes; in cells, erythrocytes would be favored over leukocytes; and in organs, the heart would be favored over the liver." According to Dr. Ames, there is a need "to set micronutrient requirements high enough to minimize DNA and mitochondrial damage." End points such as avoidance of DNA damage could be used as indicators for establishing Estimated Average Requirements (EARs) for optimal health. In the meantime, he suggests that it would be prudent to recommend general use of a multivitamin to improve intakes of critical nutrients and protect against age-related diseases. (Ames, 2006)

"The triage theory posits that, when the availability of a micronutrient is inadequate, nature ensures that micronutrient-dependent functions required for short-term survival are protected at the expense of functions whose lack has only longer-term consequences, such as the diseases associated with aging." (McCann & Ames, 2009)

A recent study suggests that multivitamins may slow the aging of chromosomes. Telomeres are tails at the ends of chromosomes (repeat sequence TTAGGG) that protect the chromosomes from degradation. The length of the telomere decreases with each round of cell division, which may eventually lead to the decline or death of the cell. "Therefore, telomere length has been proposed as a marker of 'biological aging.' Consistent with this hypothesis, preliminary epidemiologic studies have related shorter telomeres to higher mortality and higher risk of some age-related chronic diseases. Experimental evidence suggests that oxidative stress and chronic inflammation contribute to the attrition of telomeres. Several micronutrients, such as antioxidant vitamins and minerals, can modulate the states of oxidative stress and chronic inflammation and therefore may affect telomere length." (Xu, Parks, et al., 2009) In a study of 586 women in the Sister Study (healthy sisters of breast cancer patients), researchers examined the association of multivitamin use with telomere length. Sixty-five percent of the women used multivitamins at least once a month, and 74 percent of the supplement users took them on a daily basis. In general, the use of multivitamin supplements was associated with longer telomere length. Daily users had five percent longer telomeres than non-users, a difference which corresponds to about 9.8 years of age-related telomere loss. (Xu, Parks, et al., 2009) Protection against telomere aging has also been associated with other nutrients, including marine omega-3 fatty acids. (Farzaneh-Far, Lin, et al., 2010)

Bottom Line

Vitamins and essential minerals are constantly utilized by the body in producing energy to keep the system operating, in synthesizing and maintaining blood and skin and muscle and bone, in making DNA and proteins and enzymes to support cell growth and reproduction, and in supporting the physical and cognitive capabilities that make life both possible and enjoyable. Without adequate amounts of all of these nutrients, energy, productivity, and mental function decline. Some nutrients may also provide protection against the development of chronic disease, but that would be an added benefit and is not the reason they are considered essential. It is worth some effort to ensure adequate nutrient intakes to optimize function and promote overall health. That effort includes trying to get the best possible diet and may also include the rational use of nutritional supplements to fill nutrient gaps.

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