HUMAN NUTRITION: AN OVERVIEW

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Keywords: Nutrition, essential nutrients, global food supply, food and nutrition security, nutrition interventions, malnutrition, dietary intake, low birth weight, bioavailability, dietary fibre, aging, breast feeding, public health, reproductive performance, body mass, deficiencies, agro-ecological zones, chronic diseases, hypertension, cancer, cardio-vascular disease, diabetes, bones, cognitive competence

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Summary

Human nutrition is as old as humankind and has evolved as lifestyles and primary food sources have changed from those of primary hunting and gathering of animal and wild vegetation for nourishment to domesticated agriculture and significant replacement of animal protein with cereal and vegetable crops.

The science of nutrition developed in the twentieth century with the identification, isolation, elucidation of structure, synthesis and an understanding of physiological functions of the primary essential macro and micronutrients. The impact of nutritional status on major lifecycle events, including growth and development, morbidity and mortality, reproductive performance, cognitive development, work productivity and healthy aging is well documented by comparative studies in adequately and inadequately nourished populations. The consequences of under-nutrition go beyond those that limit individual development to those that impact on society and national development. Although the global food supply is adequate to feed the world's population, it is maldistributed, leaving many individuals undernourished and households subject to food and nutrition insecurity. The problem of food and nutrition insecurity relates not only to the total food supply, but also to a decline in crop diversity and changing food patterns away from traditional diets. A diversity of food and nutrition intervention strategies are available to combat malnutrition, including policies, dietary diversification through education, food fortification, use of specific nutrient supplements and public health measures to control disease. No single approach is universally assured of success. Rather, a mix of intervention strategies suited to the context in which they will be implemented and viewed within a lifecycle perspective is the most likely scenario to sustainable improvement in human nutrition, including the prevention of nutrition-related chronic diseases.

1. Background

1.1. Nutrition during the past

The history of human nutrition spans many millennia and records a variety of sources of nourishment. Archeological and fossil records date the emergence of behaviorally modern human beings *(Homo sapiens)* at about 50 000 to 40 000 BC. For the next 20 000 years of human progression in the Cro-Magnon period, people hunted large mammals such as mammoths, horses, bison and caribou and their meat contributed as much as 50% to human nourishment. In addition, wild fruits, leaves and nuts were gathered and stored for consumption during harsh ice-age winters. Pounding, scraping, roasting and occasionally baking prepared food for consumption. During the Mesolithic period (20 000 BC to 8000 BC), the bow and arrow was added to the hunter's toolkit enabling humans to successfully kill fleet-footed game, such as gazelle, antelope and deer. As for gathering food, by 17 000 BC human populations were scavenging wild grains, including wheat and barley, which archeological evidence suggests had become a common food source by 13 000 BC. The practice of processing edible grain by grinding into flour emerged, as grains increasingly became an important source of food (see *Historical Origins of Agriculture*).

Around 10 000 BC, sometime during the Neolithic period, the expanding human population necessitated a more efficient means of acquiring food. This increase in population resulted in the first agricultural transformation, i.e. domestication of plants and animals for food (see *Animal Husbandry, Nomadic Breeding and Domestication of Animals*). Hence, as the ice age diminished and merged into the Neolithic period, many large species of game became extinct, making it more difficult to rely so heavily on this source of nourishment, while wild grasses and cereals became more prominent food sources. This encouraged and fuelled the transition of human lifestyles to agriculture and animal husbandry. While hunting and gathering had supported an estimated one person per 1200 ha, farming could nourish an estimated hundred-fold more people. The unqualified success of these new means of providing food for human populations spread relatively rapidly. By 9000 BC sheep and goats had been domesticated; by 7000 BC wheat, barley and legumes were being extensively cultivated; and by 5000 BC agriculture had spread to all the inhabited continents except Australia (see *Historical Origins of Agriculture*).

The history of nutrition during the first millennium that records different dietary patterns and their associations with health and disease, is traceable through fossil records, art, literature and medical treatises. Based on experience, our recent ancestors had devised ways of managing their health problems, many of which were associated with foods. For example, physician followers of Hypocrites 2400 years ago advised symptomatic patients to eat or place on the eye the juice from liver of a black ox or cock to relieve symptoms of poor dim light vision. Anemia symptoms were to be lessened by placing iron filings in a glass of wine before drinking; and goitre was said to be responsive to chewing on seaweed or a burnt sponge. Only centuries later was the science understood that underpinned the practice; liver concentrated vitamin A necessary for the visual cycle; acidity of wine solubilized iron making it more readily absorbed; and, seaweed and sponges concentrate iodine needed for thyroid function.

As advances in chemistry and technological breakthroughs, such as the microscope, occurred in the sixteenth to nineteenth centuries; myth and dogma increasingly were replaced by science. For example, many similarities observed in the latter decade of the nineteenth century between symptoms occurring in animals and humans consuming similar types of diets were relieved by addition of similar kinds of dietary factors. Notable examples were the simple observations of Eijkman, and later Griinj, that the neurological symptoms in chickens and in humans consuming polished rice diets responded to feeding rice hulls or unpolished rice, respectively. The concept of essential dietary components, therefore, was recognized at the end of the nineteenth century.

Early in the twentieth century purified diets fed to animals were shown to be inadequate for growth and survival at rates comparable to those fed the same diet with small amounts of milk or egg added. The detective work to identify the essential dietary components greatly accelerated when rat colonies were acknowledged as valid for research studies, substituting for more expensive, cumbersome, time consuming studies using large animals as research models in the emerging science of nutrition. Nearly all of the nutrients currently known to be essential in diets for support of growth, development, reproduction and health were described, identified, isolated, synthesized, and many biochemical functions elucidated, in the first six decades of the twentieth century. Subsequent decades have seen the science of nutrition follow two complementary tracks; the first pursuing biochemical and other molecular mechanisms involving specific nutrients and the second pursuing the relationship of specific foods and dietary patterns to health and normal development.

1.2. Nutrition and today's society

The nutritional sciences today encompass a range of scientific disciplines that pertain to food, the nutrients and components contained therein, how these are utilized to support physiological processes and promote health, and the role food plays within a societal context. Today it is generally recognized that in spite of incredible scientific and technological advances that have overcome global food shortages, many people still do not benefit from an adequate and health-promoting diet. Culture and individual dietary practices and restrictions affect nutrient intake, and various health-related conditions affect requirements. Distribution and access to food for economic, market infrastructure and other reasons also are among many contributing constraints. Political factors play an important role in nutrition, and certainly, regional military clashes have contributed to displacement of persons and production of famine conditions, particularly in developing countries that have marginally sufficient agriculture production and marginal dietary sufficiency.

Nonetheless, changes in the global health dynamics during the twentieth century have been characterized by notable achievements such as a major shift from high levels of mortality to high levels of morbidity, which it is hoped, will also begin to decline as the twenty-first century proceeds. Perhaps the single greatest achievement of the modern era for human development has been the nearly universal reduction in death rates and the substantial increase in life expectancy (see *World Demography and Food Supply).* Good nutrition is recognised as a major contributing factor in mortality reduction, and nutrition research continues to demonstrate that diets play a major role in disease prevention. Indeed, about half of deaths in people under age 65 years are estimated to result from diseases in which diet plays a major role. These deaths are considered premature and preventable through optimizing diets and formulating effective health policies. When the focus is widened to include disease-related disability, the proportion of disabilities preventable through dietary modification is even greater.

Access to adequate food and nutrition conceptually is more and more recognized as a human right. In reality, however, although the world today produces enough food to feed all its inhabitants, many millions continue to suffer from malnutrition and associated ailments. This situation increasingly becomes unacceptable as science further clarifies the role of nutrition in longevity, long-term health, susceptibility to infection, and normal growth and development of children. The issue of adequate nutrition for all people in the world is more pressing than ever before. Furthermore, recent research that quantifies associations between nutritional status, work and mental performance and the social and economic growth of nations reinforces the urgent need to address the pandemic of malnutrition that afflicts many developing countries and deprived populations. Adequate nutrition, therefore, should be seen politically as an issue of development for both individuals and nations and the major challenge for the decades ahead.

2. Biochemistry of Nutrients in Foods

2.1. Classification of essential nutrients

The credibility of nutrition as a science gained momentum in the twentieth century with the systematic study of essential components of food and their physiological significance as constituents providing energy and supporting growth and development, reproduction, and maintenance of body functions. Typically, dietary nutrients are categorized as macronutrients (protein, carbohydrate and fat) that are needed in large amounts to provide energy and building units for tissue structure and physiological functions, and micronutrients (vitamins and minerals) that are needed in small amounts to facilitate metabolic processes and serve structural needs. Table 1 summarizes some significant developments in the history of vitamins gained through application of reductionism research during the first 75 years of the twentieth century.

Vitamin	Discovery	Isolation	Structure Elucidated	Synthesis
Vitamin A	1909	1931	1931	1947
Pro vitamin A	1928	1931	1930	1950
Vitamin D	1918	1932	1936	1959
Vitamin E	1922	1936	1938	1938
Vitamin K	1929	1939	1939	1939
Vitamin B_1	1897	1926	1936	1936
Vitamin B_2	1920	1933	1935	1935

Niacin	1936	1935	1937	1894
Vitamin B_6	1934	1938	1938	1939
Vitamin B_{12}	1926	1948	1956	1972
Folic acid	1941	1941	1946	1946
Pantothenic acid	1931	1938	1940	1940
Biotin	1931	1935	1942	1943
Choline	1862			1866
Vitamin C	1912	1928	1933	1933

Source: Adapted from Machlin, Annals NY Acad. Sci., vol. 669:3, 1992

Table 1. Historical account of vitamin chemistry.

Controlled feeding studies in humans and/or animals allowed vitamins and other nutrients isolated from foods to be classified into those that are indispensable (essential) and dispensable (non-essential) on the basis of metabolic outcomes, e.g. growth, balance and turnover studies. Indispensable nutrients were defined as those that had to come from food or supplements, whereas the body, if necessary, could synthesize in amounts needed the dispensable nutrients. Both essential and non-essential components of fat and protein, and digestible carbohydrate were recognized as providers of energy for immediate use and storage fuel for later use. A third category of conditional essentiality was later recognized to account for interactions among some nutrients that allowed synthesis from precursors when necessary (e.g. niacin from tryptophan, arginine from ornithine), for genetic defects (e.g. homocystinuria or maple syrup urine disease), for some pathological states (e.g. glutamine in chronic hypermetabolic states of infection and injury), or for accelerated growth needs (e.g. prematurity). Such conditions could modify whether or not certain nutrients were dispensable.

Currently the concept of essentiality is undergoing additional refinement as essential adequate requirements (EARs) for nutrients are established based on functional outcomes, and then used as the base for establishing recommended dietary intakes(RDIs and RDAs). Table 2 provides a list of nutrients currently thought to be essential for humans. The concept of essentiality, however, may evolve even further as the science base accumulates for some phytonutrients/phytochemicals in foods that provide health-benefits beyond consideration of essentiality. Obviously, a correct assessment of nutrient intake—quantity, quality and bioavailability—is essential in understanding and evaluating nutritional status of individuals, populations and the epidemiology of nutritional disease.

Water	Vitamins
Energy sources	• Vitamins A, D, E, K
Amino acids	• Ascorbic acid
• Histidine	• Thiamin
• Isoleucine	• Riboflavin
• Leucine	• Niacin
• Lysine	• Vitamin B_6 (pyridoxine)
• Methionine	• Vitamin B_{12} (cobalamin)

• Phenylananine	• Pantothenic acid
• Threonine	• Folic acid
• Tryptophan	• Biotin
• Valine	Minerals
Fatty acids	• Calcium, phosphorus, magnesium, iron
• Linoleic	Trace minerals
• α-Linolenic	• Zinc, Copper, Manganese, Iodine, Selenium, Molybdenum, Chromium
Electrolytes	Ultra-trace-minerals
• Sodium, Potassium, Chloride	• Many under study

Source: Adapted from Harper in Shils et al, Modern Nutrition in Health and Disease, 1998

Table 2. Nutrients known to be essential for humans.

At the applied level, prominent nutritionists recognized around 1930 that due to the wide diversity in nutrient density of particular foods, variety in consumption patterns was prudent to assure humans' nutrient needs would be adequately met. Even so, among industrialized countries, nutrient fortification of several processed foods commonly eaten, e.g. flours, cereals, margarine and dairy products, was promoted to reduce risk of inadequate nutrient intake. This strategy persists today in industrialized countries, but it is less common in less-industrialized countries where the prevalence of nutritional deficiencies remains high but where there is only limited centralized food processing and distribution. The last twenty-five years, particularly the last decade, has seen a resurgence in the industrialized world of interest in health-promoting qualities present in less refined and natural whole foods and, therefore, in promoting dietary diversification. FAO and WHO promote food-based dietary guidelines and many countries have adopted or are in the process of adapting such guidelines to their dietary patterns. Hopefully this trend will become the model for health-promoting consumption patterns, thus averting the degenerative disease-promoting effects associated with typical Westernized diets (see *Nutrition and Human Life Stages*).

2.2. Macronutrients

2.2.1 Proteins

Proteins are commonly found in animal tissue and their products (e.g. meat, eggs, and milk), and in vegetables, such as cereal grains and legumes. They are indispensable structural and functional components of all cells and intimately involved in almost all physiological functions. Human tissue is comprised of combinations of 20 amino acids arranged in sequences and the three-dimensional structures are unique to their functions, e.g. in muscle contraction, neuronal transmission, and glucose metabolism. Humans cannot endogenously generate sufficient amounts of the nine essential amino acids shown in Table 2. They must come from foods consumed. The remaining 11 amino acids can be synthesized by the body provided sufficient non-essential nitrogen is present. It is important however, not to confuse dietary essentiality with metabolic essentiality, e.g. all the amino acids are metabolically essential (indispensable) to support a full range of normal metabolic interactions. As sources of energy, when there is a deficit from other sources, proteins provided 4 kcal per gram. Excessive protein consumption can stress kidney function for elimination of nitrogen metabolites, contribute to obesity risk, and, in some instances, contribute to risk of degenerative diseases.

2.2.2. Carbohydrates.

Digestible carbohydrates are the most important immediate source of energy supporting all functions in the human body (they provide 4 kcal per gram), and non-digestible carbohydrates (fibre or non-glycemic carbohydrates) that assist in regulating bowel functions and modifying the colonic microflora. They are not essential in the same sense as essential amino acids or fatty acids, which must come from the diet, but it is advisable that diets include some carbohydrate for health and well being. When digestible carbohydrates are consumed in excess of energy needs, they are converted to fat for storage.

Carbohydrates have traditionally been classified as simple and complex based on their structural units (e.g. mono-, di-, oligo-, and polysaccharides) or the complexity of structures. However, defining the appropriate category for diverse sources has varied across regions and led to confusion, e.g. does complex carbohydrate refer to starch only or all polysaccharides? A recent FAO/WHO expert consultation proposed a new classification of the major dietary carbohydrates to avoid such confusion. The proposed new classification is based on the degree of polymerization as shown in Table 3.

Class (and degree of polymerization)	Subgroup	Components
Sugars (1-2)	Monosaccharides	Glucose, galactose, fructose
	Disaccharides	Sucrose
	Polyols	Sorbitol
Oligosaccharides (3-9)	Malto-oligosaccharides	Maltodextrins
	Other oligosaccharides	Raffinose, stachyose, fructo-oligosaccharides
Polysaccharides (>9)	Starch	Amylose, amylopectin, modified starch
	Non-starch polysaccharides	Cellulose, hemicellulose, pectins, hydrocolloids

Source: FAO/WHO. 1998. Carbohydrates in Human Nutrition: Report of a Joint FAO/WHO Expert Consultation, 14-18 April 1997, Rome. FAO Food and Nutrition Paper No. 66. Rome

Table 3. Classification of the major dietary carbohydrates.

The term dietary fiber denotes a wide range of carbohydrates that are not absorbed in the small intestine, e.g. they are non-glycemic carbohydrates and their components. These substances play an important role in regulating bowel function and are now recognized as also able to exert positive health effects, such as stimulating the growth of certain bacteria in the colon that appear to protect against colonization by pathogenic species.

2.2.3. Lipids

Lipids include groups of hydrophobic substances that range from fats (glycerol esters) that are a high-density storage form of energy to sterols and their esters that play many important structural and functional roles. Their insolubility in the aqueous medium of body fluids is of major importance in their transport and metabolism. Storage fats are primarily in the form of glycerol esters of three fatty acids (triglycerides) whereas functional fats are generally in the form of mono-or diglycerol esters of fatty acids with the other position(s) esterified with at least one non-fatty acid group, e.g. phospholipids or sterol esters. Glycerides formed from saturated and/or unsaturated fatty acids have different consistencies at room temperature (a shorter chain length and greater unsaturation associated with greater fluidity), and they are metabolized differently because of their differing chemical structures. Saturated fatty acids have all their carbon atoms maximally bound while unsaturated fatty acids have one (monounsaturated) or more (polyunsaturated) double bonds between carbon atoms. Although the carbon chain length of common fatty acids in foods varies from four to twenty-four, most found in human tissues consist of 14-22 carbons.

Among the polyunsaturated fatty acids, the eighteen carbon family of linolenate (18:2n-6) and α-linolenate (18:3n-3) are essential because they cannot be synthesized by most mammals, including human. Linolenate is needed for infant growth and can serve as a source of energy, as well as serving along with its elongated and desaturated products as integral parts of cell-membrane lipoproteins, skin ceramides, prostaglandins and other icosanoids. α-Linolenate is not required for growth or reproduction but its desaturation and elongation products are found extensively in the brain and retina. Prolonged deficiency in these products (e.g. docosahexanoic acids [DHA]) results in reduced visual acuity in primates and there are some reports of a similar effect in humans.

Research has shown that diets high in saturated fats increase the risk for cancer, heart disease and some other pathological states, whereas unsaturated fatty acids, particularly DHA, are beneficial for health. Fish oils are good sources of DHA and vegetable oils are sources of other unsaturated fatty acids. Processing vegetable oils to form solid or semisolid margarine, however, can cause isomerization to form trans-fatty acids, which are associated with increased risk of heart disease.

Though an excess of fat in the diet can lead to health problems, a small amount is needed for optimal health. Triglycerides satisfy more than half of all basal energy requirements, providing an average 9 kcal per gram. In addition, lipolytic products of fat digestion are critical to the formation of water-miscible micelles needed to facilitate the digestion and absorption of fat-soluble vitamins, carotenoids and other lipid-soluble substances, including drugs. Fat also serves as a thermal blanket insulating against heat loss and as a protective cushion from collision injuries. In the absence of dietary fat, the body can synthesize fatty acids, except for the essential n-3 and n-6 family, from products generated from catabolism of proteins and carbohydrates.

Very hydrophobic lipids, such as cholesterol and triglycerides, play important roles in cellular membranes and hormone production or as energy sources, respectively. For transport in body fluids, they are solubilized by combining with protein to form lipoproteins of varied densities, e.g. high density lipoproteins (HDLs), low density lipoproteins (LDLs), very low density lipoproteins (VLDLs), and chylomicrons. HDL and LDL primarily transport cholesterol, whereas VLDLs and chylomicrons primarily transport triglycerides. These transport molecules are considered the scavengers that remove excess cholesterol in the arteries and deposit it in the liver for processing and subsequent removal in bile secretions.

2.3. Micronutrients

Vitamins and minerals play essential catalytic roles in metabolism and have other functional roles as well. Although needed in minute amounts, most vitamins are not synthesized in the human body in sufficient quantity, and, therefore, together with essential minerals must be obtained from food or other exogenous sources. There are two main classes of vitamins: fat-soluble and water-soluble.

- Fat-soluble vitamins A (and provitamin-A carotenoids), D,E, and K need protein or other water-miscible carriers for transport, are not easily excreted, and when in excess are stored in body tissues.
- Water-soluble vitamins are those of the B-vitamin family-thaimine (B_1),riboflavin (B_2), niacin, folate, pyridoxine (B_6), cyanocobalamin (B_{12}), pantothenic acid- and vitamin C. These are readily transported and excreted, and accumulate only to a limited extend in body tissues, i.e. they should be consumed almost daily to assure needs are met.

Essential minerals listed in Table 2 are generally classified according to the relative quantities in which they are needed (see *Adequate Diet of Essential Nutrients for Healthy People*). Those needed in milligram amounts or more, are distinguished from those needed in trace amounts, e.g. micrograms, which are distinguished from those needed in ultra-trace amounts, e.g. nanograms, and from electrolytes. These minerals serve a wide range of functions:

- As structural parts of the skeleton (e.g. calcium);
- As transporters of blood gases (e.g. iron);
- As integral parts of enzymes and hormones (e.g. selenium and iodine, respectively), and
- As essential to maintaining critical electrolyte balances for nerve transmission and muscle contraction (e.g. sodium, potassium); and many more important metabolic processes.

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Biographical Sketches

Barbara A. Underwood, Ph.D., Adjunct Professor Pediatrics (Nutrition), Columbia University, has worked internationally on problems of maternal/child malnutrition for over four decades. She has conducted research in South and Southeast Asia, Latin America and Africa, particularly on micronutrient deficiency, malnutrition and vitamin A metabolism. She has held professorial positions at University of Maryland, Columbia University, Pennsylvania State University and the Massachusetts Institute of Technology, and served as Assistant Director, International Programs for the National Eye Institute, NIH. She served the WHO Nutrition Program as focal point for micronutrients and was a Scholar in Residence, Institute of Medicine. Dr. Underwood has published over 150 research papers, book chapters and reviews. She continues to consult for WHO, UNICEF and the United Nations University, and to serve on Advisory Boards for various organizations. From 1997 to 2001 she was President, International Union of Nutritional Sciences (IUNS).

Osman M. Galal, M.D., Ph.D., UCLA School of Public Health, has more than 30 years of experience in research, teaching, administration and consultation in the field of international health and nutrition. His background is in pediatrics as well as human health and nutrition. He has worked in West Africa and has extensive experience in the Middle East. Dr. Galal was the Director of the National Nutrition Institute of the Ministry of Health in Egypt in the early 1980s. He initiated and served as a consultant for the "Combating Diarrhea" project in Egypt. He was also the Egyptian Principal Investigator of USAID's Collaborative Research Support Program in Human Nutrition in the 1980s through the early 1990s. Apart from advancing the understanding of consequences of mild to moderate malnutrition in developing countries, this program was also instrumental in setting up an infrastructure capability in nutritional sciences at national institutes. He has worked as a consultant for UNICEF and the World Bank, and is currently consulting for FAO on establishing a monitoring system for recording food security among Palestinians. At UCLA, he was the Principal Investigator and the Director of the Minority Fogarty Training Grant for 5 years (1997-2002). He currently has active research projects in child survival programs and nutrition surveillance in the Middle East. Recently he conducted a workshop, "School Children: Health and Nutrition" with the participation of 30 nutrition experts from six continents. The participants presented research on nutrition and school performance, and concluded the importance of improving health and nutritional status of infants and pre-school children as a prerequisite for efficient learning in school. Dr. Galal has authored over seventy papers and chapters in publications. He is the Secretary General of the International Union of Nutritional Sciences (IUNS) and has served since 1997. He consults regularly on nutrition and child health issues for various international agencies and national governments. He is a member of the WHO Expert Advisory Panel on Nutrition.