

Principles of human nutrition

Michael EJ Lean

Abstract

We rely on the foods we eat to provide all the building blocks for tissue growth and reproduction, the energy required for all metabolism, functions and activities, and the compounds that are 'essential' for normal metabolism but cannot be synthesized by humans. Nutritional science covers all the processes involved in achieving a healthy balance between requirements and the supply of nutrients, at the right time and in appropriate proportions, at cellular, organ, whole-body and group/population levels. Nutritional status (a composite of what we eat, what we are and what we can do) should be assessed in all patients. Good clinical and public health practice requires first an awareness that nutrition is important, and then the application of simple screening, and detailed evaluation when appropriate. Nutritional status is commonly affected by illness and by treatment. Nutrition is only occasionally a sole cause or treatment of disease, but is frequently an important contributor to disease aetiology and to management, especially for prevention.

Keywords Food; growth development; MPCP; nutritional status

Foods, nutrients and health

Taken to the simplest level, under evolutionary pressures a species has relatively few absolute requirements. Its individuals must grow to sufficient size, but not too big, to survive, and function long enough to reproduce and raise the next generation into independence. A species is then likely to be successful if individuals are not damagingly stressed, and enjoy well-being but have the capacity to withstand threats. During evolution, the greatest threat is always famine or food shortage through composition, and a vital strength of humans has been our diversity of metabolic and functional capacities, allowing different strategies for surviving food shortages.

As animals, we are not able to extract energy for activity and function out of sunlight, so we rely on ingested material for both the building blocks and the synthetic energy for all functions. It is thus evident that foods, through the nutrients they contain, are vital to enable every function of which we are

Michael EJ Lean MA MBChir MD FRCP FRSE is Professor of Human Nutrition at the University of Glasgow, UK, and Honorary Consultant Physician at Glasgow Royal Infirmary, UK. He holds adjunct and visiting professorships at the Universities of Otago (New Zealand), Sydney (Australia) and Memphis (USA). Competing interests: Professor Lean has in the last 5 years received research funding, contributed to Advisory Boards and undertaken consultancy for several pharmaceutical and food companies – Novo Nordisk, Orexigen, Janssen, Novartis, Eli Lilly, Counterweight Ltd, and holds shares in Eat Balanced, the Scottish company that developed and markets nutritionally balanced pizzas and other meals.

Key points

- Human nutrition determines growth and development. It is required for all metabolic processes for metabolism and activities, and for resistance to and recovery from injury and illness
- Nutritional status, of individuals and population groups, incorporates (1) what we eat (diet), (2) what we are (body and tissue composition) and (3) what we can do (metabolic and physical functions), to determine all the elements of health (physical, mental, social, and genomic)

genetically capable – physical, mental and social. Food is necessary for growth, tissue maintenance and repair, and of course reproduction. Inherent in this is the concept of 'health', of optimizing our capacity for physical, mental, social and genomic functions, and for resisting and recovering from diseases and injuries.

Nutritional science covers all the processes involved in achieving a healthy balance between our requirements and the provision of nutrients, supplied at the right time and in appropriate proportions at cellular, organ, whole-body and group/population levels. It considers a range of factors that influence digestion, absorption, metabolic transformation and functions. Food is at the core of nutrition. Health is essential for normal growth and development, for current health and for future health (including the future adult health of fetus and child). It is a critical element in the social health of communities as well as the health (at cellular, organ and whole-person levels) of the individuals within them.

All foods, whether from animal, vegetable or mixed sources, ultimately derive from sunlight and photosynthesis to build larger molecules from carbon dioxide and water, plus nitrogen and trace elements extracted from air, soil and water sources (Figure 1). This is the work of plants. Animals are obligatorily dependent on plants for nutrition, although many animals take short cuts by consuming ready-made animal material. Foods are almost exclusively composites of many compounds, known as 'nutrients', that contribute to function and metabolism. Purified sucrose, used as table sugar, is the only food that is a single nutrient (a carbohydrate). There are otherwise no 'protein foods' or 'carbohydrate foods', and most domestic fats or oils also contain small amounts of other nutrients. Small amounts are often important in nutrition.

Foods are most often consumed in combination, as 'eating occasions' or meals. It is useful to consider the meal as the smallest unit of nutrition for which nutritional analysis is appropriate. Individual foods can be analysed in terms of their nutrient compositions, but this is the realm of food science rather than nutrition. Nutrients usefully contribute biologically after they are consumed, as long as they are adequately separated by digestion, digested and absorbed. The nutrients must be 'available'. Some are partly metabolized within the bowel or only partially absorbed, so less than 100% of the nutrients in a food are available to the consumer.

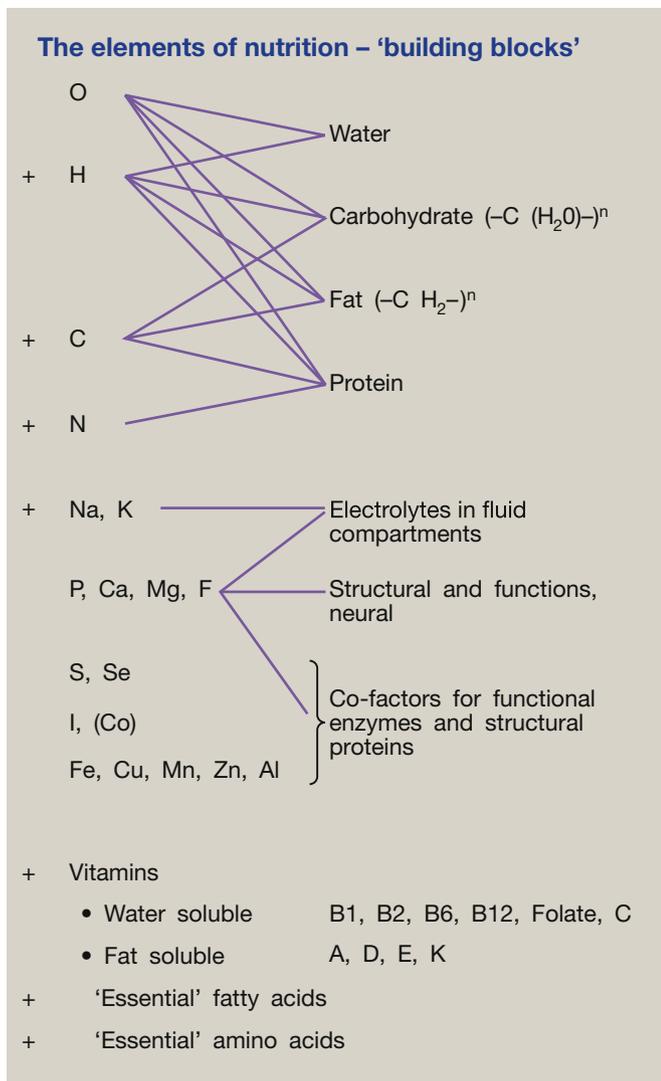


Figure 1

Some foods also contain non-nutrient components, such as particles of grit in stone-ground grains, that are not absorbed. Some components, such as inert metals from the soil, are absorbed but serve no function and are excreted unchanged. Some nutrients are not absorbed but still have a function (e.g. most dietary fibre, which provides the vital energy source for bowel microbiota). There are more bacterial cells in the gut than there are human cells in the body, and they generate waste products, such as volatile fatty acids, which are valuable to gut health and which are absorbed as an energy source for humans.

Nutrients that contribute energy (calories) are known as macronutrients: fats, proteins and carbohydrates (total carbohydrates include a proportion of dietary fibre) (Table 1). All are composed of just carbon, oxygen, hydrogen and small amounts of nitrogen. Some of the molecules in each nutrient category have other functions.

A very small number of the organic molecules present in certain foods are ‘essential’, which means that they are necessary for biological function but cannot be synthesized by human biochemistry from other compounds. As a broad generalization,

Energy contents of macronutrients

	Energy (kcal/g)
Fat	9
Protein	4
Carbohydrate	3.75
Dietary fibre	2–3

Table 1

the ‘essential’ nutrients are ones that evolution has allowed to be unsynthesizable because they were widely available in our evolutionary diets. These comprise the essential amino acids and fatty acids necessary to construct all the lipid and protein molecules needed in a fully functional healthy body, and the vitamins, first discovered in the early 20th century and required from foods in tiny amounts. There are technically no ‘essential’ dietary carbohydrate molecules, although dietary fibre is necessary for normal bowel function, and soluble dietary fibre (e.g. from legumes) has an important modifying function on metabolic processes that affect carbohydrate and lipid metabolism. The brain oxidizes almost exclusively glucose, which is usually derived from dietary carbohydrates but can theoretically come from protein and glycerol. Given time to adapt, the brain can also oxidize ketone bodies if glucose is unavailable, but sudden hypoglycaemia can be fatal. Without essential fatty acids, amino acids or vitamins in the diet, classical deficiency states develop. In addition to vitamins, a relatively large number of essential trace elements, required from foods, serve as co-factors for the enzyme functions of specific proteins (Figure 1). An insufficiency of trace elements in the diet also leads to classical deficiency states (Table 2).¹

Vitamins and trace elements are examples of functional food components known as ‘micronutrients’ (see Micronutrient deficiencies, vitamin pills and nutritional supplements, pp. 145–151 of this issue). Adding these as fortified foods or as supplements benefits individuals who are deficient, or replenishes stores if they are low. However, there is no benefit from the excessive supply of micronutrients, and storage capacity does not need to be completely occupied. Moreover, excessive consumption of certain micronutrients can interfere with the absorption of others. For example, iron and zinc share a transport mechanism for absorption, and excess of one can compromise absorption of the other. Only some micronutrients are stored in the body (Table 2); these can be intermittently provided from specific foods in the diet, but micronutrients with low storage capacity are best consumed daily.

All organic compounds from foods are ultimately either excreted intact (a minority) or metabolized and converted to fuels for oxidation. A variety of non-essential functional compounds in foods also contribute to health. These are sometimes not classified as nutrients but are ultimately metabolized and oxidized. Examples include the non-pro-vitamin A carotenoids (e.g. lutein, lycopene), the large family of phenolic compounds with antioxidant and other functions, and caffeine. Some act in the same way as drugs to modify cellular biochemistry; indeed, caffeine is used as a prescription drug as well as a component of

Nutrients and clinical deficiency diseases

Nutrient	Maximum storage capacity	Consequence of deficiency
Oxygen	3–5 minutes	Rapid progressive failure and death of metabolically active organs, especially brain and heart
Macronutrients		
Carbohydrate	12–48 hours as glycogen	No absolute requirement, but inadequate carbohydrate supply reduces glycogen stores and limits exercise capacity. Switch is made to dependence on oxidative metabolism of fats and ketone
	5–10 minutes as glucose in blood	Effects of sudden hypoglycaemia similar to oxygen deficiency. Rapid failure and death of vital organs, especially brain and heart. Some rescue is possible using ketones from fat metabolism if hypoglycaemia develops slowly
Fat	6–20 weeks depending on fatness	No absolute requirement for fat as an energy source. Ultimately, as body fat falls, there is a switch to excess catabolism of lean tissue
Protein	None	Slow loss of nitrogen from protein metabolism. Loss of enzymatic capacity and structure, e.g. bones
Micronutrients		
Fat-soluble vitamins A, D, E, K	Weeks/months	Specific deficiency diseases (vitamin D synthesized by sunlight on skin)
Water-soluble C, B ₁ , B ₂ , B ₆	Days/weeks	Specific deficiency diseases
Vitamin B ₁₂	Months	Subacute combined degeneration of the spinal cord, anaemia (B ₁₂ is also synthesized by gut bacteria)
Minerals		
Iodine, iron, calcium, magnesium	Weeks	Hypothyroidism, anaemia, osteopenia
Zinc, copper, manganese, sulphur, selenium	None	Substitution in enzymes, with reduced function capacity

Table 2

coffee and other beverages. The boundary between definitions and the trade regulation of foods and drugs is sometimes poorly defined.

Some foods contain toxic compounds, either as natural components of the food source, or from bacterial or other contaminants. As an example, sodium, in salt, is required in only tiny amounts, and in the amounts usually consumed in diets in developed countries increases blood pressure and the risk of cardiovascular disease. Iron is extremely toxic in excess. Cooking and food-processing can alter compounds in foods and cause them to become harmful: for example, browning of certain foods during baking forms advanced glycation end products and carcinogenic acrylamide, barbecuing creates carcinogenic cyclic amines, and nitrite treatment to preserve meat forms carcinogenic nitrosamines.

Finally, food is not just a source of nutrients, but a source of pleasure and social cohesion. Humans use meals to unite and reaffirm families, friendships and societies. Food is highly profitable and forms the largest sector in the commercial economy, consuming budgets greater than those allocated to defence or transport. Being central to population health, foods and nutrition are also important to health promotion. However, the scale of the food industry, and pursuit of profit in a market economy, place constraints on the industry and on governments when changes are urged by experts to improve health.

Nutrition has few dramatic or rapid effects on health except through starvation. The only real nutritional emergency in clinical medicine is thiamine deficiency, most often seen in alcoholics who will develop Wernicke’s encephalopathy, which can cause permanent brain damage if not treated immediately. The consequences of suboptimal diet composition for most disease causation are slow to develop, difficult to attribute in individual patients and easy to ignore, but the cumulative impact of diet composition on the health of communities is very large. In seeking ways to exploit this impact, ‘dietary advice’ and health promotion are likely to benefit only highly literate, educated and health-aware sectors of the population. To improve the health of the most vulnerable, and more socially deprived sectors, small changes in the composition of foods and meals supplied by industry and eaten regularly by large numbers of people would be effective, and everyone else’s health would also improve. Until very recently, governments have been reluctant to act through interventions to require changes in food and meal compositions. However, socially inclusive ‘health by stealth’ methods are now beginning to emerge, for example through taxation of high-sugar foods, which has forced manufacturers to modify product compositions. These early measures alone are unlikely to modify the obesity epidemic, but they mark a recognition by governments that the collateral damage to health (or ‘externalities’) from an unregulated food market are no longer acceptable to society.

When unusual toxic compounds are discovered in food groups (e.g. the recent identification of acrylamide in baked and manufactured foods such as breakfast cereals) government agencies and industry are quick to alter manufacturing processes to prevent the problem, but action over the much greater impact of high-salt, or high-saturated fat content of foods and meals has not led to decisive action on food manufacturing. Disproportionate media space and government funding are allocated to 'food scares', when compared with the promotion of solid, evidence-based advice for long-term healthful eating.

Nutritional status

The nutritional status of an individual defines, and is defined by, the capacity to perform the range of functions required in health, and the metabolic competence to respond to stresses. Nutritional status is assessed as a composite of three components (Table 3). (1) 'What we eat' (our diet composition) determines the availability and supply of nutrients (filtered by food choice). This has direct, defining, influences on (2) 'what we are' (body composition) – including our size and relative amounts of tissues (e.g. body fat, muscle mass), and also the body's content of micronutrients and compounds that require them (e.g. iron stores and haemoglobin or red blood cells). This also affects (3) 'what we can do' (our functional capacity), which includes physical, mental, metabolic and social functions.

An appreciation of the circular complexity of nutritional status is important to understand any disease and optimize management. It is not sufficient to assess just one or two of the three components in Table 3. For example, a low-zinc diet and thin skin both impair resistance to infections such as cellulitis. Impaired functional capacity then has influences on growth and body composition, and on the capacity to absorb and metabolize nutrients.

While it is possible to measure certain elements within each of the three components, and these may point towards a nutritional problem, it is not possible to 'measure' nutritional status with any simple test. Its assessment requires clinical skills and experience. Although body compositional measures are valuable, biochemical measurements are of rather limited value in assessing nutritional status. Many micronutrient assays, for

example, are heavily affected by acute-phase responses during illness, so do not reflect whole-body status. Moreover, functional micronutrient deficiencies can occur despite body stores being adequate; for example, vitamin A deficiency can occur during illness if its transport to tissues is frustrated by a decline in retinol-binding protein.

Nutritional economy

Nutrition provides for growth and development, and for maintenance of the *milieu interieur*. The inward flow, functions and fates of nutrients can be considered and traced individually, but all nutrients contribute synergistically to bodily processes, often simultaneously but sometimes at different rates. These nutritional processes can be viewed as a large set of interacting economies, and the languages of economics and nutrition coincide. The principles of nutritional economy to provide for growth, development and reproduction can be applied at every level of biological organization: for isolated cells, for whole organs (excepting reproduction), for the whole body, and for communities.

For optimal function and the capacity to respond to changes, challenges and disease, each of these organizational levels must be in nutritional balance – when intake equals demand – with adequate storage (investment) for nutrients whose demand may vary suddenly. If demand exceeds supply, function declines and a debt may be incurred. In some situations, one 'commodity' (e.g. sulphur, copper) can be used in place of the preferred nutrient (selenium, manganese) as a co-factor in an enzyme. In this case, function can be maintained, but usually at a cost – with loss of efficiency. For optimal efficiency, food choices must supply the correct amount of energy (calories) from an ideal mix of macronutrients, and also all the required (essential) nutrients, each at the right rate.

In practice, there is no single ideal food or nutrient mix intake for individuals or for communities. Instead, there are ranges of intakes for different nutrients that can all provide for excellent function across the range of needs. For very specialized functional demands, however, nutrient demands may vary, or become more narrowly defined. Examples include pregnancy, during or after illness, and for very high-level athletic performance. In these situations, there is never a need for radical changes: nutrition modifies performance or health only by small effects that develop over time.

Nutritional flexibility

Biological processes and the activities of human life continue constantly, with some fluctuations in rates (e.g. metabolic rate falls at night and rises with exercise, but can never stop). However, food is not consumed constantly. Food availability, choice and consumption are intermittent and vary enormously, so the supply of nutrients never matches exactly the pattern of temporal demand. To accommodate this mismatch, the nutritional economy uses a number of strategies to optimize function.

The demand for energy is absolute. If calories are used, they must be matched by supply over time, but energy can be stored. An adult stores some carbohydrate as glycogen in muscles and liver, but only sufficient to provide about 1000–1500 kcal. That is enough for perhaps 2 hours of strenuous activity. Glycogen has

The interrelated components which define nutritional status

What we eat – diet composition

- Self-reported intake (retrospective)
- Objectively observed food consumption
- Estimated or measured nutrient consumption

What we are – body composition

- Water content, chemical composition
- 2-compartment (fat/lean tissue) imaging
- Bone mass/specific tissue composition

What we (can) do – functions

- Metabolic, cellular functions
- Organ/whole-body function
- Physical, mental and social activities

Table 3

to be provided from dietary carbohydrate, or some proteins, as carbohydrate cannot be synthesized from fats. In general, glycogen is stored at each meal and provides a ready supply in case of sudden need before the next meal. If the diet is very low in carbohydrate, glycogen stores become depleted and the capacity for physical activity, and avoidance of hypoglycaemia, is reduced. For the longer term, energy is stored as triglycerides (triacylglycerols) in body fat (adipose tissue), of which there is usually sufficient to supply energy needs for several weeks.

Nutrition in disease

In the past, the nutritional requirements of individuals were expressed as ‘recommended daily amounts’, which were directed towards ensuring sufficiency to avert the classical deficiency diseases, with some excess allowed depending on the potential toxicity of some nutrients. In general, all metallic trace elements are toxic in very high amounts, and fat-soluble vitamins also accumulate to exceed storage capacity and become toxic. There is a range of safe intakes for most micronutrients. This type of approach does not apply to the energy-yielding macronutrients (proteins, carbohydrates) except for their essential fatty acids and amino acids this is because even a tiny mismatch between requirement and intake, if sustained, leads to catastrophic weight loss or gain.

More recently, average nutrient requirements have been compiled as ‘Dietary Reference Values’ (DRVs), with predicted energy (calorie) requirement from measurements of metabolic rate, and a range of intakes for other nutrients that are compatible with good health (between a lower Reference Nutrient Intake (RNI) – sufficient for only 5% of individuals – and an upper RNI – sufficient for 95% of individuals). The published DRVs also go some way towards defining the balance of some nutrients that would optimize long-term health (e.g. fat <35%, and carbohydrate >50% of dietary energy).

Evidence is very scanty on ‘optimal’ intakes of most nutrients, although some examples can be described. Some nutrients interact; for example, although polyunsaturated fats have advantages over saturated fats for preventing cardiovascular disease, they are easily oxidized and should always be consumed with an antioxidant such as vitamin E. Although essential micronutrients are required for health, the symptoms of deficiency diseases are non-specific and seldom the result of deficiency. Consuming extra micronutrients as supplements has no health value and can be hazardous. For example, large-scale clinical trials have found that giving high-dose antioxidant Vitamins A, C, E to middle-aged smokers increased cancers and mortality rather than reducing them.

Nutrition contributes to the causes of disease as well as occasionally to its management. The classical nutritional deficiency states (Table 2) are rare, although iron, iodine and vitamin A deficiencies are still major global problems and remain common in our developed societies. Relative deficiency can, however, contribute to the aetiology of many multifactorial diseases. In principle, deficiency can result from reduced intake or from increased consumption of a nutrient, for a wide range of behavioural, metabolic and social reasons. Diseases commonly

modify food choices – both total amount and nutrient profiles – and some drugs or other treatments can impede or alter food consumption.

It is not possible here to describe all the detailed ways in which diet can be modified to help in recovery from illness or management of chronic metabolic diseases; that is the discipline of dietetics. However, some general points should be considered in the management of every patient, with any illness:

- Is the patient currently malnourished? Consider energy balance, body composition and functional signs of malnutrition such as lethargy and physical weakness (see Malnutrition and undernutrition, pp. 152–158 of this issue).
- Does the patient’s current nutritional status (Table 3) suggest a risk of malnutrition that requires nutritional support to avoid deterioration?
- Does nutrition contribute aetiological to the diagnosis, or to clinical complications?
- Is the illness likely to interfere with food consumption or food choice, so that nutritional support or guidance might help to aid recovery and avoid relapse?

Repeated surveys and audits have shown how, in the drama of hospital admission, nutritional status is often ignored and even profound malnutrition can go undocumented. If this diagnosis is missed or neglected, there are likely to be profound consequences for the patient, as well as medico-legal consequences. Malnourished patients become ill more frequently and for longer, commonly lose more weight and can be depleted of many nutrients during an acute illness. Nutritional support and supplementation can improve the outcome.

To improve the detection, diagnosis and, ultimately, management and secondary prevention of malnutrition, a simple ‘nutrition score’ (e.g. using the Malnutrition Universal Screening Tool (MUST)²) should be calculated for all patients admitted to hospital. There is a strong case that all sick and elderly individuals in the community should also be assessed using a validated instrument. This will guide referral to a dietitian for formal assessment of nutritional status and clinical consequences. ◆

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