NUTRIENTS

DR. EVA KUDLOVA

Proteins, fat and carbohydrates are the **main nutrients**. Their proportion in the diet is important and may be expressed as the ratio of energy provided. Protein should provide 8–15% energy, fat 25-30% and carbohydrates 55-60%. Whereas the fat in the body can be derived from dietary carbohydrates and the carbohydrates from proteins, the proteins of the body are dependent for their formation and maintenance on the protein in food. Other indispensable nutrients are **minerals, trace elements, vitamins and water**.

Most of countries have set up standards by age and sex groups for intake of nutrients by healthy persons. **Recommended daily allowances** (RDA) serve as a reference base from current nutrition research for intake levels of the essential nutrients judged to be adequate for meeting the known nutritional needs of the healthy population groups. RDA also serve as guidelines for maintaining healthy populations. RDA are not intended to indicate individual requirements, for these are highly variable, nor do they set clinical needs, which are determined by individual health problems. Recommended dietary allowances are similar in different countries but may vary a little according to their purpose and use.

1 Energy

Energy is measured in terms of heat equivalent joule (J) or calories: 1 calorie equals 4.184 joules. One gram of carbohydrate yields 17 kJ (4 kcal), 1 g of protein yields 17 kJ (4 kcal), 1 g of fat yields 38 kJ (9 kcal), and 1 g of alcohol yields 29 kJ (7 kcal). When food is not available, the body draws on its own stores to meet energy needs, *Carbohydrate* stores (glycogen) are most easily depleted and thus the first to undergo catabolism. *Fat* stores (adipose tissue) are larger and catabolized once glycogen stores are depleted. *Protein* stores (body tissue) contain a fair amount of potential energy and are catabolized also after carbohydrate is depleted, along with fat stores.

Energy is needed for:

1. The **basal metabolic rate** (BMR) is the amount of energy required to maintain the body at rest. Lean body mass is the major factor influencing BMR because the metabolic activity in lean

tissues is greater than that in less active tissues such as fat or bones. BMR rises during growth periods, pregnancy, and lactation. Fever increases the BMR about 10% for each 1 °C rise in body temperature. Also diseases involving increased cell activity such as cancer, cardiac failure, hypertension and respiratory problems usually increase the BMR.

2. Food intake requires energy to meet the many activities of digestion, absorption and transport of the nutrients. This overall stimulating effect of food is called **dietary thermo genesis** and accounts for additional 5% - 10% of BMR

3. **Physical activities** require additional 30 – 70% of BMR depending on the intensity.

Deficiency leads to malnutrition.

Excess leads to obesity with all its consequences.

2 Proteins

Composition: Proteins consist of large molecules composed of **amino acids** bound together by peptide linkages. The human body has a certain limited powers of converting one amino acid into another. However, there are several amino acids (essential), which the body cannot make for itself and so must obtain from the diet. **Complete proteins**, usually of animal origin, are those that contain all essential amino acids in sufficient quantity and ratio to meet the body's needs. **Incomplete proteins**, mostly of plant origin, are those deficient in one or more of the essential amino acids. A mixture of plant proteins may provide sufficient amount of essential amino acids, if planned carefully, especially to cover the **"limiting" essential amino acid** the one occurring in the smallest amount and most likely to be deficient. This capacity of proteins is known as their supplementary value.

Function: Every cell in the body is partly composed of proteins, which are subject to continuous wear and replacement. The proteins of the body are inevitably dependent for their formation and maintenance on the protein in food. Proteins function in **building tissues**, performing various **specific additional physiologic roles**, and **sometimes providing energy**. The primary function of dietary protein is to supply building material for growth and maintenance of body tissue. Also protein supplies amino acids for other essential nitrogen-containing substances such as enzymes and hormones. In addition, protein antibodies provide essential components of the body’s immune system, and plasma proteins guard water balance. Some amino acids also perform other important physiologic and metabolic roles. For example, methionine is an agent in the formation of choline, which is a precursor of acetylcholine, one of the major neurotransmitters in the brain.

Metabolism: Proteins undergo hydrolysis by proteolytic enzymes in the gastrointestinal tract, ultimately resulting in amino acids, which contribute to the a common collective metabolic "pool" of amino acids throughout the body available for use.

Requirement: Commonly accepted protein requirement ranges from 0.7 to 1 g/kg of ideal body weight. The requirements of children, pregnant and lactating women are higher. The contribution made by proteins to the energy value of a well-balanced diet should be 10-15%.

Deficiency:

- Protein energy malnutrition,
- Impairment of immunity,
- Inadequate growth and renewal of cells and tissues,
- Impairment of enzyme synthesis and function,
- Changes in the bio transformation of xenobiotics,
- Changes in hormonal functions,
- Impairment of spermatogenesis,
- Increased cancer risk due to deficit of choline and methionine.

Excess: The intake of protein is substantially above the requirement in some developed countries. The excess of animal protein is usually accompanied by a substantial intake of fat (meat, meat and milk products) with all its risks. Upper limit of safe protein intake has not been yet established. The intake of protein above 2 g/kg leads to increased levels of nitrogenous substances, increased glomerular filtration in the kidneys and changes in liver functions.

3 Lipids

Lipids include a chemically varied group of substances that have different metabolism and functions. The most common fats (solid) or oils (liquid) are a mixture of **triacylglycerols** (triglyceride) with minor amounts of other lipids. The type of fatty acids is a determinant for the biological importance of the fat in the organism. Three classes of **fatty acids** (FA) are described according to the number of double bonds between the carbon atoms. In a **saturated** FA (e.g. palmitic, stearic, arachidic acids) there are none; in an unsaturated FA there may be one (**monoenoic acids** e.g. oleic acid) or two or more (**polyenoic acids** or PUFA = Poly Unsaturated Fatty Acids, e.g. linoleic, linolenic, arachidonic acids). All essential fatty acids that have to be provided by the diet belong to the n-3 and n-6 classes according to the position of the first double bond relative to the methyl carbon atom. They play critical roles in membrane structure and as precursors of eicosanoids, which are potent and highly reactive compounds. A number of studies have shown that the consumption of foods (such as oil-rich fish) containing the long-chain n-3 fatty acids eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) is associated with decreased risk of coronary heart disease.

Cholesterol, a steroid, occurs naturally in all animal foods. There is none in plant foods. Its main food sources are egg yolks and organ meats such as liver and kidneys. In addition to a dietary source, the body obtains cholesterol by synthesis. This takes place mainly in the liver but also in all cells of the body. Cholesterol has three distinct roles in the body (1) as a structural component of all cell membranes (2) as a precursor of bile acids and (3) as a precursor of adrenal and gonadal hormones and of vitamin D.

Function: Food fats supply a source of fuel for the body to store and burn as needed for **energy.** Food fat yields 38 kJ/g. Fats in the diet supply give flavour to food that, together with the slower gastric emptying time, contributes to a feeling of satisfaction that lasts longer than does the feeling of satisfaction after eating carbohydrates. Food fats supply the **essential fatty acids,** especially linoleic acid, and are **carriers of fat-soluble vitamins**. Body fats in the adipose tissue form the chief **store of energy**; a web-like padding of adipose tissue surrounds vital organs such as the kidneys, **protecting** them from mechanical shock and providing a **supportive structure**; the layer of fat directly underneath the skin **controls body temperature**. In all tissues lipids are a **main part of the structure of cell membranes** helping transport materials and metabolites across cell membranes. Lipoproteins carry fat in the blood to all cells. Lipids are the precursors from which many hormones are made.

***Metabolism*:** Most dietary fat is supplied in the form of triacylglycerols, which must be hydrolysed to fatty acids and monoacylglycerols before they can be absorbed by the enterocytes of the intestinal wall. Fatty acids are then re-esterified and enter the circulation via the lymphatic route as **chylomicrons**. **Lipoprotein lipase** located on the interior walls of the capillary blood vessels hydrolyses the triacylglycerols, releasing fatty acids. These enter the adipose tissue where they are stored, and the muscles, where they serve as fuel. The liver clears the remnants of chylomicrons, which include cholesterol and fat-soluble vitamins, within a few hours of the ingestion of a fat-containing meal. **Very low-density lipoproteins** (VLDL) are large triacylglycerol-rich particles produced in the liver from endogenous fat, as opposed to chylomicrons, which transport exogenous fat. **Low-density lipoproteins** (LDL) are the end product of VLDL metabolism. The core consists mainly of cholesterol esters. About 60-80% of cholesterol in plasma is carried by LDLs playing an important role in the development of atherosclerosis. Average LDL values vary among populations because of genetic and environmental factors; however, diet is probably a major determinant of these values. **High-**

density lipoproteins (HDL) carry 15-40% of plasma cholesterol. In humans, LDL delivers cholesterol to the liver and HDL may transfer cholesterol to other lipoprotein particles. There is evidence that HDL actively protects vessel walls, presumably by reverse cholesterol transport, that is, transport from the periphery to the liver. Within populations, high levels of HDL are strongly associated with reduced risk of chronic heart disease.

Requirement: The daily fat intake should be 0.3 g animal and 0.4 g vegetable fat per kg of bodyweight, not more than 30% of energy. Intakes of saturated and polyunsaturated fatty acids should provide less than 10% of energy each and monounsaturated fatty acids 10-15% of energy. Cholesterol should be restricted to 300 mg/day or less. On the other hand, adequate amounts of dietary fat are essential for health and should not supply less than 20% of energy intake.

Excessive fat intake has been linked to increased risk of **obesity, coronary heart disease,** and **certain types of cancer**. The mechanisms by which these are linked are complex and varied. Elevated levels of serum cholesterol and low-density lipoprotein constitute major risk factors for atherosclerosis and coronary heart disease. The degree of risk of these and other factors may vary according to type and level of fatty acid intakes, percentage of energy from total fat, dietary cholesterol, lipoprotein levels, intake of antioxidants and dietary fibre, activity levels, and health status.

4 Carbohydrates

Monosaccharides are the simplest form of carbohydrate. ***Glucose*** is mainly created in the body from the digestion of starch and disaccharides. The normal blood sugar range is about 3.9 - 6.1 mmol/litre. ***Fructose*** is found in fruits and honey. In human metabolism fructose is converted to glucose. ***Galactose*** is not found free in foods but is produced in digestion from lactose (milk sugar) and is then changed to glucose for energy. **Disaccharides** are composed of two monosaccharides linked together. ***Sucrose***, the most prevalent disaccharide, is the common "table sugar". ***Lactose*** is the sugar in milk. **Polysaccharides** are made up of many single saccharide units. The most important polysaccharide in human nutrition is ***starch***. The animal storage compound comparable to starch in plants is ***glycogen***. It is formed during cell metabolism and stored in relatively small amount in the liver and muscle tissues. These stores help to sustain normal blood glucose level during fasting periods such as sleep hours and provide immediate energy for muscle action.

Metabolism: Starch and disaccharides are broken down by digestive enzymes, into monosaccharides, then absorbed and thus made available to the tissues as a source of energy.

Function: The primary function of carbohydrates in human nutrition is to provide energy. They also prevent the breaking down of fats and proteins for energy, which would result in excessive production of toxic metabolic by products. Carbohydrates provide a great part of the energy in all human diets. In the diets of poor people up to 85% of the energy may come from carbohydrates. On the other hand, in the diets of the rich in many countries, the proportion may be as low as 40%. Neither of these extremes is desirable. A high intake of sucrose occurs in many populations. It contributes to the excessive intake of energy; it is linked to glucose intolerance, hyperlipidaemia and increases the occurrence of dental caries.
Requirement: Optimum intake of carbohydrates is 4 - 6 g/kg body weight, 55 -60% of the energy intake. The intake of sucrose should not exceed 10 %.

Dietary fibre can be defined as plant substances, mostly polysaccharides, resistant to the human digestive enzymes. It may be classed as: (1) **cellulose**; (2) **non-cellulose polysaccharides**, including hemicelluloses, pectins, gums, mucilages, and algal substances; and (3) the single non-carbohydrate member, **lignin**.
Dietary sources of fibre: Whole grain cereal products, pulses, vegetables and fruits. Food of animal origin does not contain fibre.
Function: Dietary fibre produces various effects on the food consumed and its fate in the body. Most of them are caused by its water holding capacity and binding effect.
Requirement: 30 g/day
Excessive intake reduces nutrient bioavailability.

Table 1 Fibre - modes of action

- Prolongs chewing and swallowing movements, thus increasing satiety rate,
- Increases diameter of the intestinal lumen, thus allowing intestinal tract to contract more, propelling contents more rapidly, and inhibiting segmentation,
- Increases water absorption, resulting in a larger, softer stool,
- Slows fat absorption by forming gel matrices in the intestine, thus increasing faecal fat content,
- Binds cholesterol preventing absorption,
- In epidemiological studies usually observed with reduced fat intake, thus contributes to reducing triglyceride and cholesterol levels,
- Slows carbohydrate absorption by
  - delaying gastric emptying time,
  - forming gels with pectin in the intestine, thus impeding carbohydrate absorption,
  - "protecting" carbohydrates from enzymatic activity with fibrous coat, and

- allowing "protected" carbohydrates to escape into large colon where they are digested by bacteria,

- Reduces postprandial blood sugar levels, insulin requirements and increases insulin sensitivity,
- Reduces insulin levels,
- Forms gel that bind bile acids, inhibits recirculation of bile acids, thus alters bacterial metabolism of bile acids, which may affect the structure of the colon, its cell turnover rate, and function,
- Shortens the duration of the contact of the intestinal wall with carcinogens,
- Binds toxic components of the contents of intestine.

5 Minerals and trace elements

The human body is composed mainly of carbon, hydrogen, oxygen and nitrogen. Other indispensable elements are minerals and trace elements. **Minerals** (sodium, potassium, calcium, phosphorus, magnesium, and sulphur) are present in tens up to thousand grams. **Trace elements** (iron, iodine, zinc, selenium, and other) are present in tiny amounts. They have important, not yet fully clarified functions in metabolic processes. A considerable importance is attributed to some of the trace elements in the primary prevention of tumours and cardiovascular diseases. Their positive effect, however, occurs only when the intake is within an acceptable range. Lower as well as higher intakes are deleterious for health (see also Chapter Malnutrition).

The adult body contains about 1,200 g of **calcium**, approximately 99% of which is present in the skeleton. Bone is constantly turning over, a continuous process of resorption and formation. In children and adolescents, the rate of formation of bone mineral predominates over the rate of resorption. In later life, the resorption predominates over formation. Therefore, in normal aging, there is a gradual loss of bone. The remaining 12 g of body calcium is found in the extracellular fluids, intracellular structures, and cell membranes. This extra skeletal calcium plays an essential role in such vital functions as nerve conduction, muscle contraction, blood clotting, and membrane permeability. *Optimal calcium intake* is important to maximize and maintain peak adult bone mass and to minimize bone loss among older persons, both of which are key to reducing the risk of osteoporosis. Calcium requirements vary. The greatest needs are during the period of rapid growth in adolescence, during pregnancy and lactation, and in later adult life. The average daily intake of calcium is closely related to dairy products consumption, which in most European countries and North America provides more than half of the dietary calcium.

Most of the **sodium** intake comes from salt, which is added to almost all forms of processed foods, particularly preserved meat and fish, pickles, spices, soups and sauces. Daily intake of table salt should not exceed 6 grams as it is associated with hypertension and possibly stomach cancer.

Table 2.3 Function, main sources and deficiency of minerals

Function	**Source**	**Deficiency**
Potassium		
Primarily intracellular ion. Muscle contraction, nerve impulse conduction, intracellular osmotic pressure and fluid balance, heart rhythm	Present in all plant foods Important sources are vegetables, fruits, pulses, nuts	Caused by gastrointestinal losses (vomiting, diarrhoea), urine (Cushing's syndrome, osmotic diuresis, diuretics) or skin losses (excessive sweating, burns) Spasms, headache, together with water loss signs of dehydration
Phosphorus		
Together with calcium component of bones and teeth, forms phospholipids, phosphoproteins, nucleic acids, enzymes, macroergic bonds (ATP)	Present in nearly all foods Major contributors are protein rich foods and cereal grains. Polyphosphates and other compounds are often used as food additives.	Does not occur
Magnesium		
As $Mg\text{-}ATP^{2-}$, essential for all biosynthetic processes: glycolysis, formation of cyclic AMP, energy dependent membrane transport, and transmission of the genetic code; > 300 enzymes are known to be activated by magnesium; maintenance of electrical potentials of nerve and muscle membranes and for transmission of impulses across neuromuscular junctions	Green leaves (chlorophyll component), potato, nuts, legumes and whole grains	Purely dietary magnesium deficiency has not been reported in people consuming natural diets
Sodium		
Extracellular cation but small amounts in muscle and cartilage; osmotic pressure, acid base balance, water balance, muscle and nerve irritability	Mostly table salt and salty foods, Meat, eggs, milk	Caused by gastrointestinal losses (vomiting, diarrhoea), urine (Cushing's syndrome, osmotic diuresis, diuretics) Irritability, muscle weakness, paralysis impaired heart function
Calcium		
Together with phosphorus component of bones and teeth, decreases neuromuscular irritability, important for heart function, blood clotting, prevention of colorectal carcinoma	Milk, milk products, leafy green vegetables. Water is a variable source	Together with other factors associated with osteomalacia, osteoporosis, rickets, Increases neuromuscular irritability, tachycardia, impaired blood clotting, increased carcinoma of colon
Sulphur		
Component of amino acids methionin and cystein, role in detoxication processes as a component of glutathion	Protein foods	Does not occur

Iron

Function: Iron is a constituent of haemoglobin, myoglobin, and a number of enzymes. In addition, as much as 30% of the body iron is found in storage forms such as ferritin and haemosiderin mainly in the spleen, liver and bone marrow, and a small amount is associated with the blood transport protein transferrin. Body iron content is regulated mainly through changes in the amount of iron absorbed by the intestinal mucosa. Body stores influence the absorption of iron, by the amount and chemical nature of iron in the ingested food, and by a variety of dietary factors that increase or decrease the availability of iron for absorption. In iron deficiency, the efficiency of iron absorption increases. However this response may not be sufficient to prevent anaemia in subjects whose intake of available iron is marginal. Similarly, intestinal regulation is not sufficient to prevent excessive body accumulation of iron in the presence of continued high levels of iron in the diet.

Sources: Meat, eggs, vegetables and cereals (especially fortified cereal products in some countries) are the principal dietary sources. Haem and non-haem forms of iron are absorbed by different mechanism. Haem iron is highly absorbable and averages about 40% of the total iron in all animal tissues. The remaining 60% of the iron in animal tissues and all iron in vegetable products are present as non-haem compounds. The absorption of non-haem iron is low but can be enhanced by some organic acids, especially ascorbic acid. It may be substantially decreased by phytates, calcium phosphate, bran, polyphenols in teas, and grains.

Deficiency: Three stages of impaired status have been identified. In the first stage, iron stores are diminished, as reflected in a fall of plasma ferritin to levels below 12 μg/L, but no functional impairment is evident. The second stage is recognized by iron-deficient erythropoiesis, in which the haemoglobin level is within the 95% reference range for age and sex but red cell protoporphyrine levels are elevated, transferrin saturation is reduced to less than 16% in adults, and work capacity performance may be impaired. In the third stage, iron deficiency anaemia, total blood haemoglobin levels are reduced below normal values for age and sex of the subject. Severe iron deficiency anaemia is characterized by small red cells (microcytosis) with low haemoglobin (hypochromia).

Iron deficiency may be observed primarily during four periods of life: a) from about 6 months to 4 years of age, because the iron content of milk is low, the body is growing rapidly, and body reserves of iron are often insufficient to meet needs beyond 6 months; b) during the rapid growth of early adolescence, because of needs of an expanding red cell mass and the need to deposit iron in myoglobin c) during female reproductive period, because of menstrual iron losses; and d) during pregnancy, because of the expanding blood volume of the mother, the demands of the foetus and placenta, and blood losses during childbirth.

Excess: In people without genetic defects that increase the iron absorption there are no reports of iron toxicity from foods other than long-term ingestion of home brews made in iron vessels. On the other hand there are cases of poisoning mainly among young children who ingest the medicinal iron supplements. The lethal dose of ferrous sulphate for a 2-year-old child is approximately 3 g, for adults it ranges from 200 to 250 mg/kg body weight. Some people are genetically at risk from iron overload or haemochromatosis. Idiopathic haemochromatosis, which can result in the failure of multiple organ systems, is the result of an inborn error of metabolism, which leads to enhanced iron absorption.

Table 3 Function, main sources and deficiency of trace elements

Function	Source	Deficiency
Copper		
Constituent of many enzymes, participation in iron binding in haemoglobin, formation of pigments, hair, important for immune functions	Organ meats, especially liver, are the richest sources followed by seafood, nuts and seeds.	Exceptional. Described in malnourished children: anaemia, bone demineralisation, impaired immunity, hair and nail growth
Chromium		
Trivalent form potentiates the action of insulin, increases glucose tolerance Six-valent form is an allergen and carcinogen	Yeasts, meat, cheese, nuts	Decreased glucose tolerance, hyperlipidaemia, acceleration of atherosclerotic changes
Fluoride		
Bone and teeth formation	Water tea, fish if consumed with bones	Increased caries formation Poor bone mineralization
Iodine		
Component of thyroid hormones	Sea fish and seafood, eggs, milk, iodised salt (25 mg/kg)	Cretinism, goitre, miscarriages stillbirth, mental retardation, deaf-mutism
Iron		
Constituent of haemoglobin, myoglobin and antioxidative enzymes	Meat, liver, eggs, wholegrain products, leafy vegetables, pulses	Anaemia, impaired psychomotor development, decreased physical activity and resistance to fatigue
Manganese		
Important for the normal function of the central nervous system, bone structure, involved in oxidative phosphorylation as a constituent of enzymes	All unprocessed food, especially wholegrain products, pulses and nuts	Purely dietary deficiency has not been reported in people consuming natural diets
Selenium		
Present at the active site of glutathione peroxidase that catalyses the breakdown of hydroperoxides and thus prevents the damage caused by free radicals, positively influences immunity, probably anticarcinogenic action	Seafood, kidney and liver; Grains and other seeds are variable source, depending on the selenium content of the soils in which they are grown	Decreased lymphocytes and natural killer activity, decreased interferon formation Keshan and Kashin Beck diseases
Zinc		
Involved in over 200 enzyme reactions, component of superoxid-dismutase preventing oxidation stress, positively influences tissue growth and healing, participates in insulin formation and spermatogenesis	Meat, liver, eggs and seafood, Whole grain products contain zinc in a less available form	Immunodeficiency, growth retardation, hypogonadism, hypospermia, skin lesions, alopecia, anorexia, hypogeusia

6 Vitamins

The vitamins are organic substances which the body requires in small amounts for its metabolism, yet cannot make it for itself, at least not in sufficient quantity. Vitamins are usually grouped and distinguished according to their solubility in either fat or water. **Fat-soluble vitamins A, D, E,** and **K** are closely associated with lipids in their fate in the body. They can be stored, and their functions are generally related to structural activities. The **water-soluble vitamins** are the **B-complex** ones and **C**. These have fewer problems in absorption and transport. They cannot be stored except in the general "tissue saturation" sense. The B vitamins function mainly as coenzyme factors in cell metabolism. Vitamin C is a vital structural agent.

Table 4 Function, main sources and deficiency of water-soluble vitamins

Function	**Source**	**Deficiency**
Vitamin C (ascorbic acid)		
Antioxidant, iron absorption, collagen formation, hydroxylation reactions, beta-oxidation of fatty acids, activity of microsomal enzymes, detoxication of xenobiotics, blocks the formation of nitrosamines,	Citrus fruits, tomatoes, berries, cabbage, green vegetables. Potatoes in the Czech Republic due to their high consumption	Scorbut in extreme conditions, Hypovitaminosis: gum bleeding, impaired healing, decreased immunity, fatigue
Vitamin B1 (thiamine)		
Coenzyme for many reactions in carbohydrate metabolism.	Whole grain cereals, organ meats (liver), pork, milk, legumes, nuts and seeds	Beriberi in extreme conditions, Wernicke Korsakoff syndrome among chronic alcoholics
Vitamin B2 (riboflavin)		
Enzymes involved in oxidation-reduction reactions that enter many metabolic pathways and affect cellular respiration	Milk, cheese, liver and other organs, meat, eggs, fish, green leafy vegetables	Angular stomatitis, glossitis, dermatitis
Vitamin B6 (pyridoxine)		
Role in protein, glycogen metabolism, sphingolipid and haem synthesis; formation of amines, including epinephrine, norepinephrine and serotonin,	Meat, liver, kidney, whole grains, soybeans, nuts, fish, poultry and green vegetables.	Inflammation of the tongue, lesions of the lips and corners of the mouth, and peripheral neuropathy
Vitamin B12 (cyanokobalamin)		
Participates in haematopoesis, nucleic acids synthesis, role in the function of peripheral nervous system	Meat, fish, eggs, milk, cheese Utilization depends on correct gastric secretion	Pernicious anaemia, neuropathy
Niacin		
Involved in glycolysis, fatty acids metabolism, tissue respiration and detoxification	Meat, fish, moderate amounts of niacin of variable bioavailability in Cereals	Pellagra in extreme conditions when maize is the staple food
Folic acid		
Coenzymes in the transfer of single-carbon atoms in reactions essential to the metabolism of several amino acids and to nucleic acid synthesis.	Variety of foods, including green leafy vegetables, nuts, liver, cereals, cheese, fruits, yeast, beans, peas.	Macrocytic anaemia Glossitis, pharyngeal ulcers, impaired immunity
Biotin		
Cofactor for several carboxylases used in fatty acid synthesis and metabolism, gluconeogenesis and branched-chain amino acid metabolism	Liver, egg yolk, soy flour, cereals and yeasts The availability of biotin depends partly on binders in food	Deficiency is rare; Fatigue, nausea, anorexia, muscle pains, paraesthesia, dry scaly skin, alopecia, anaemia and elevated serum cholesterol
Panthotenic acid		
As a component of CoA and its esters, is essential in lipid and carbohydrate metabolism,	Widely distributed, especially in animal products, whole grains, and legumes	Very rare; Dermatitis, hair follicles atrophy, Syndrome of "burning feet" paraesthesia, of

	war

Table 5 Function, main sources and deficiency of fat-soluble vitamins

Function	Source	Deficiency
Vitamin A (retinol), carotene		
Component of retinal pigments, participates in bone and tooth development, formation and maturation of epithelia, antioxidant, supports immune function	Retinol: liver, milk products, fish oils, Carotene: yellow and red fruits and vegetables, leafy vegetables	Xerophtalmia, night blindness, keratomalacia leading to blindness, skin changes, Reduced resistance to infection
Vitamin D		
Participates in the metabolism of calcium and phosphorus	Oily fish, egg yolk, supplements, food fortification Exposure to sunlight.	Rickets in children, osteomalacia in adults
Vitamin E (tocoferol)		
Protects lipids of the cell membranes from oxidation by free radicals; together with vitamin C blocks the formation of nitrosamines; plays important roles in other biological processes	Oils, germ oils of various seeds, green leafy vegetables, nuts, legumes	Usually develops only in premature infants or in adults with malabsortion
Vitamin K		
Prothrombin formation, coagulation; factors II, VII, IX and X are vitamin K dependent.	Green leafy vegetables, pulses, margarines and vegetable oils; Bacteria in the intestine synthesise vitamin K and may contribute to the available pool in the body.	Haemorrhagic disease of the newborn, Bleeding in impaired resorption (lack of bile acids) or after an antibiotic therapy (lack of intestinal bacteria)