Chapter 1: Nutrition and Diet

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Abstract

Diet and nutrition are fundamental in maintaining the general and oral health of populations. Diet refers to the total amount of food consumed by individuals; whereas nutrition is the process of utilising food for the growth, metabolism and repair of tissues. The relationship between diet and nutrition and health is two-way; health status can be affected by nutrient deficiency and vice versa. Dietary guidelines have been developed to provide evidence-based food and beverage recommendations for populations; aiming to promote a diet that meets the nutrient requirement for all nutrients and to prevent diet-related diseases such as dental caries and obesity. Based on the amount required by the human body for normal metabolism, growth and physical well-being, nutrients are divided into two categories: macronutrients consisting of proteins, carbohydrates and fat; and micronutrients consisting of vitamins and minerals. Fats are the most energy-dense macronutrient; whereas carbohydrates are quantitatively the most important dietary energy source for most populations. Proteins are vital structural and functional components within every cell of the body and are essential for growth and repair and maintenance of health. Vitamins and minerals, which are found in small amounts in most foods, are essential for normal metabolic function. This chapter provides an overview of the impact of nutrients on general and oral health, with an emphasis on macronutrients.

Introduction

Diet and nutrition are fundamental in maintaining the general and oral health of populations. Diet refers to the total amount of food consumed by individuals, and consists of different constituents which can be governed by many factors such as environmental conditions and availability of food, religious beliefs, socioeconomic status, etc. Nutrition is the process of utilising food for the growth, metabolism and repair of tissues, and involves ingestion, digestion, absorption, transport, incorporation into cells, and excretion. Main dietary patterns include: omnivorous (a mixed diet of both plant and animal origin), flexitarian (a plant-based diet with occasional animal protein consumption), pescatarian (a plant-based diet with a restriction of animal protein consumption to fish and seafood only), pollotarian (a plant-based diet with a restriction of animal protein consumption to poultry and fowl only), lacto-ovo vegetarian (a vegetarian diet with inclusion of dairy products such as cheese, milk and yogurt), and vegan (a restricted vegetarian diet with exclusion of any animal products or their by-products such as gelatine). Convenience, life style, nutritional status, health and weight management are among the factors which passively influence the dietary pattern of each individual.

The relationship between diet and nutrition and health is two-way. Health status can be affected by nutrient deficiency and vice versa, i.e. any health problem (including oral health) may affect nutritional status. The main nutrients required to maintain general and oral health are proteins, carbohydrates, fat, vitamins and minerals. Many health conditions such as obesity, diabetes, cardiovascular disease, several forms of cancer, osteoporosis and dental disease can be avoided by having a well-planned nourishing diet. A 'Balanced Diet' consists of a variety of different types of food that provides sufficient amounts of nutrients required to maintain good health. All over the world, dietary guidelines have been produced by governments to provide evidence-based food and beverage recommendations for populations. These recommendations aim to promote a diet that meets the requirement for energy as well as all essential nutrients to prevent diet-related diseases such as obesity and dental caries. Examples of such guidelines are the 'Eatwell Guide' recommended by Public Health England (PHE) (Figure 1) [1] and the Healthy Eating Pyramid of the Australian Nutrition Foundation [2]; illustrating different types of foods and drinks and the proportions in which they should be consumed. These guidelines are based on human nutritional requirements and dietary recommendations which are termed Nutrient Reference Values (NRVs) in Australia [3], Dietary Reference Values (DRVs) in the UK [4, 5] and Dietary Reference Intakes (DRIs) in the USA [6]. These values are general terms comprising a series of estimates of the amount of energy and nutrients required by healthy individuals of different age groups (Table 1).

Nutrients are divided into two categories, macronutrients and micronutrients, based on the amount required by the human body for normal metabolism, growth and physical well-being. The impact of specific nutrients on oral health is considered in detail in Part 2.

Macronutrients

Carbohydrates

Carbohydrates are quantitatively the most important dietary energy source for most populations, usually contributing 55-75% of total daily energy requirements [7]. They are predominately derived from plant foods with grains and fruits as well as dairy products as the main dietary sources. Carbohydrates are composed of carbon, hydrogen and oxygen in a ratio of 1:1:2, respectively. In early nutrition text books, carbohydrates were classified into two groups: simple carbohydrates composed of monosaccharides (glucose, fructose and galactose) or disaccharides (sucrose, lactose and maltose), which are easily and quickly utilised for energy by the body, and complex carbohydrates (oligosaccharides and polysaccharides) which take longer to digest. Carbohydrates are also often classified into three groups: i) monosaccharides, ii) disaccharides and oligosaccharides, and iii) polysaccharides [8]. However, based on a Food and Agriculture Organization (FAO) and World Health Organization (WHO) joint recommendation [9], dietary carbohydrates should be classified into three groups based on their chemical forms (Figure 2), as determined by the degree of polymerization, type of linkage (α or non-α) and character of individual monomers. The precise division between these groups is not quite helpful as the physiological and health effects of carbohydrates are also determined by their physical properties, which include water solubility, gel formation, crystallization state, association with other molecules and aggregation into the complex structures of the plant cell wall [9]. In any case, the importance of these categorisations is insignificant for determining the nutritional quality of carbohydrates; for example, fructose (a simple carbohydrate) increases blood glucose slowly, whereas processed starches (complex carbohydrates) raise blood glucose rapidly. Glycaemic index (GI) was therefore introduced to classify different sources of carbohydrate-rich foods according to their effect on post-meal glycaemia [10]. In this categorisation, carbohydrates are ranked on a scale from 0 to 100 based on how quickly and how much they raise the levels of blood glucose after consumption: i) low GI (0-55), ii) medium GI (56-69) and high GI (70-100), where low-GI foods are those being digested and absorbed slowly and high-GI are being rapidly digested and absorbed.

The metabolism of carbohydrates starts in the mouth with mechanical and chemical digestion; mastication grinds the food into smaller fragments and salivary amylase breaks down amylose and amylopectin into smaller chains of glucose, called dextrins and maltose. Since only about five percent of starches are broken down in the mouth, starchy foods are not major risk factors, unlike simple sugars, for dental caries. Carbohydrates are mainly digested in the small intestine where monosaccharides are absorbed into the blood stream. Insulin, glucagon, and epinephrine are the hormones that control blood sugar concentrations. When blood glucose concentration is too high, insulin is secreted by the pancreas, which stimulates the transfer of glucose into the cells, especially in the liver and muscles. Almost 70% of the glucose entering the body through digestion is redistributed back into the blood, by the liver, to be used by cells and tissues or, in the case of excess, converted to glycogen and stored in muscles and the liver. In humans, the main functions of carbohydrates include the production and storage of energy. Many cells have a preference for using glucose as an energy source; in particular, the brain and white and red blood cells depend on glucose as their sole energy source.

Glucose is also required to build some important macromolecules: it is converted to ribose and deoxyribose, which are essential building blocks of ribonucleic acid (RNA), deoxyribonucleic acid (DNA) and adenosine triphosphate (ATP). In addition, glucose is used to make nicotinamide adenine dinucleotide phosphate (NADPH), an important molecule for protection against oxidative stress.

In a situation where there is insufficient carbohydrate or fat in the diet, protein is broken down to make glucose needed by the body. To spare protein for tissue synthesis, carbohydrates are therefore needed to prevent such protein breakdown for glucose production. Glucose is also required to prevent the development of ketosis, a metabolic condition resulting from a rise in the ketone bodies (acetoacetate, beta-hydroxybutyrate and acetone) in the blood, which are produced by the liver from fatty acids.

Proteins

Proteins are the most common nitrogen-containing compounds in the diet. While plant structures are mainly built on carbohydrates, proteins are vital structural and functional components within every cell of the body of humans and animals. Since most foods contain either animal or plant cells, they are natural sources of protein.

Proteins are made up of long chains of amino acids, linked by peptide bonds. The proteins in the human body are made from 20 different amino acids. Based on nutritional requirements, amino acids are categorised into three groups as: essential, semi-essential and non-essential. Essential amino acids are those that cannot be synthesised in the human body and, therefore, must be consumed through the diet. They are: methionine, threonine, tryptophan, valine, isoleucine, leucine, phenylalanine and lysine. Semi-essential amino acids, which cannot be synthesised in adequate amounts in the body and therefore require augmentation through the diet, include histidine and arginine, which are essential for children but not adults. The remaining non-essential amino acids can be synthesised in the liver from other amino acids.

All necessary amino acids should be available during the process of protein synthesis in the body. The sequence of amino acids governs the ultimate structure and function of any given protein and is regulated by a specific genetic code stored in the associated cell nucleus as DNA.

The digestion of proteins begins in the stomach when hydrochloric acid denatures proteins within food and the pepsin enzyme breaks down proteins into smaller polypeptides and their constituent amino acids. The digestion of protein continues in the small intestine by first neutralising the food-gastric juice mixture (chyme) as a result of sodium bicarbonate released by the pancreas which also helps to protect the lining of the intestine. The released digestive hormones, including secretin and cholecystokinin (CCK), in the small intestine, stimulate digestive processes to break down the proteins further. The pancreas releases most of the digestive enzymes, including the proteases trypsin, chymotrypsin, and elastase, which break complex proteins into smaller individual amino acids. The amino acids are then transported across the intestinal mucosa to different tissues of the body where they are either used in replacing damaged tissues or in the synthesis of proteins. Excess amino acids may be converted by liver enzymes into keto acids, which are used as sources of energy via the citric acid cycle, or converted into glucose or fat for storage, and urea which is excreted in urine and sweat.

All cells in the body contain proteins; certain hormones such as insulin and glucagon, as well as antibodies and almost all enzymes, are proteins. Proteins transport nutrients and oxygen in the blood and also help maintain the acid-base balance of blood and tissue fluids.

Proteins are essential for growth and repair and maintenance of health. However, a number of health concerns are associated with protein originating primarily from animal sources including: cardiovascular disease, due to the high saturated fat and cholesterol associated with animal proteins, and bone health, from bone resorption due to sulphur-containing amino acids associated with animal protein [11]. Generally, the quality of protein in the diet depends on their constituent amino acids. Compared with plant proteins, the nutritional value of animal proteins is higher because the distribution of amino acids in animal cells is similar to that in human cells [11]. Low intake of animal-sourced proteins during late pregnancy is believed to be associated with low birth weight [12]. Meat-based diets have also been shown to cause a significantly greater net protein synthesis and greater gains in lean body mass compared to vegetarian diets, which could be a function of lessened breakdown of protein with the former [13].

Fats and lipids

In biology, lipids have been loosely defined as a group of organic compounds that are insoluble in water but soluble in nonpolar solvents. Contrasting with carbohydrates, lipids are not polymers but smaller molecules extracted from the tissues of plants and animals [8]. Dietary fat includes all the lipids in plant and animal tissues that are eaten as food. Meats and dairy foods are the most obvious sources of fat, but most foods contain some fat. Vegetable sources rich in dietary fat are nuts and seeds, olives, peanuts and avocados.

Although lipids cover an extremely heterogeneous collection of molecules from a structural and functional perspective, all lipids have a polar, hydrophilic "head" and a nonpolar, hydrophobic, hydrocarbon "tail". According to their insolubility in water, lipids are commonly categorised into three major groups of simple, compound and miscellaneous lipids in some nutrition text books [8] (Figure 3). However, in the LipidBank database [14], lipids are classified based on their response to hydrolysis as: ‘simple lipids’, those yielding at most two distinct types of compound upon hydrolysis (e.g., acylglycerols: fatty acids and glycerol), ‘complex lipids’ yielding three or more products upon hydrolysis (e.g., glycerophospholipids: fatty acids, glycerol, and headgroup) and ‘derived lipids’, alcohols and fatty acids resulting from hydrolysis of simple lipids. However, the LIPID MAPS classification system has been created based on the concept of two fundamental “building blocks”: ketoacyl groups and isoprene groups [15]. Consequently, lipids are defined as small hydrophobic or amphipathic (or amphiphilic) molecules that may originate entirely or in part through condensations of thioesters and/or isoprene units [15]. Based on this classification system, lipids have been divided into eight categories: fatty acyls, glycerolipids, glycerophospholipids, sphingolipids, saccharolipids and polyketides (derived from the condensation of ketoacyl subunits); and sterol- and prenol-lipids (derived from the condensation of isoprene) [15].

Fatty acids are the key constituents of the lipids in food and the body and are categorised into three types: saturated, monounsaturated and polyunsaturated, according to the number of carbons, the number of double bonds and the position of double bonds in the molecular chain. Based on nutritional need, fatty acids are also categorised as essential and non-essential. The essential fatty acids are α-linolenic (a type of omega-3) and linoleic (a type of omega-6), which cannot be synthesised in the body and, therefore, must be obtained through the diet. The most prevalent form of dietary fat are the triglycerides which are composed of three fatty acids and a glycerol molecule.

The digestion of dietary fat starts in the stomach as its churning action helps to form an emulsion. After entering the intestine, the partially emulsified fat is mixed with bile and is further emulsified. The emulsion is hydrolysed by lipases secreted by the pancreas, converting triglyceride to monoglycerides and free fatty acids which are then absorbed by the enterocytes of the intestinal wall. Fatty acids with a chain length of less than 14 carbons enter directly into the portal vein system and are transported to the liver; whereas fatty acids with 14 or more carbons are re-esterified within the enterocyte and enter the circulation via the lymphatic route as chylomicrons. Fat soluble vitamins (vitamins A, D, E and K) and cholesterol are delivered directly to the liver as part of the chylomicron remnants [16]. Fatty acids are transported in the blood as complexes with albumin or as esterified lipids in lipoproteins.

From the endogenous fat, liver produces very-low-density lipoproteins (VLDL) which are the main carriers of triglycerides, suppling fatty acids to adipose and muscle tissues. The end products of VLDL metabolism are low-density lipoproteins (LDL), which carry approximately 60-80% of cholesterol in plasma. High-density lipoproteins (HDL) remove fat molecules (phospholipids, cholesterol, triglycerides, etc.) from the cells and tissues and transport them back to the liver [16]. Fats are an important component of diet, being the most energy-dense macronutrient. They are an essential component of cell membranes and internal fatty tissues that protect the vital organs from trauma and temperature change by providing padding and insulation. In recent years, lipid nutrition research has been focused on the role of specific fatty acids in the metabolism of cholesterol, lipoprotein and glucose. The type and amount of fatty acids in the diet has been shown to affect the plasma concentrations of LDL, VLDL, HDL, cholesterol and triglyceride [17], as well as insulin sensitivity and glucose metabolism [18]. In respect of human health, essential fatty acids are precursors to the formation of prostanoids, thromboxanes, leukotrienes and neuroprotectins, which in turn regulate key physiologic functions such as blood pressure, vessel stiffness/relaxation, thrombocyte aggregation, fibrinolytic activity, inflammatory responses and leukocyte migration [19]. Although early studies suggested that dietary saturated fats increase the risk of coronary artery disease (CAD), several recent analyses have shown that saturated fatty acids, particularly in dairy products, can improve health [20]; whereas the evidence of omega-6 polyunsaturated fatty acids (PUFAs) promoting inflammation and some diseases is growing. Oxidation of PUFAs, as well as sugars, produces various aldehydes which are known to initiate or intensify several diseases, such as: cancer, asthma, type 2 diabetes, atherosclerosis, and endothelial dysfunction [20].

Micronutrients

Vitamins and minerals are nutrients that are found in small amounts in most foods and are essential, in minute amounts, for normal metabolic function.

Vitamins are a group of organic compounds that cannot be synthesised by humans and should be provided by the diet; otherwise their deficiency could cause adverse health conditions. While vitamins have few chemical similarities, their metabolic functions have been defined in one of four general groups: i) membrane stabilisers, ii) hydrogen and electron donors and acceptors, iii) hormones and iv) coenzymes [8]. They also have important roles in gene expression in humans. Vitamins are classified into two groups based on their solubility: fat-soluble and water-soluble. The main functions and dietary sources of vitamins are presented in Table 2; with more details provided in chapter 6. The fat-soluble vitamins are absorbed passively by intestinal mucosae in the presence of fat. This group of vitamins is mainly found in the lipid portions of the cells such as membranes and lipid droplets. Fat-soluble vitamins are excreted with faeces via the enterohepatic circulation [8]. The water-soluble vitamins are also mainly absorbed by passive diffusion, except for vitamin B_1 (thiamine) which is absorbed by a sodium dependent transport mechanism and vitamin C which is absorbed by both passive diffusion and sodium dependent active transport. Vitamin B_{12}, a collective term for a group of cobalt-containing compounds known as corrinoids, is absorbed by active transport in the terminal ileum after binding to salivary haptocorrin and 'intrinsic factor' (a protein cofactor secreted by the parietal cells of stomach). The water-soluble vitamins are not stored in significant amounts in the body and are excreted in the urine [8].

In nutrition, minerals are a group of inorganic elements that cannot be made by the body and are necessary for a variety of functions, including: the formation of bones and teeth, as essential constituents of body fluids and tissues, as components of enzyme systems and for normal nerve function. Based on the quantity needed by the body, minerals have been categorised into two major groups: macro-minerals with a requirement of ≥ 100 mg/day and micro-minerals (trace elements) with a requirement of < 15 mg/day, which include ultra-trace elements that are necessary at a level of µg/day, although specific requirements have not been established for some of them (Table 3) [8]. Minerals take up 4-5% of the body weight of an average adult. Although macro-minerals occur mainly in the ionic state in the food and the body, some minerals also exist as components of organic compounds such as phospholipids and haemoglobin. They are usually absorbed in the ionic state, with heme iron being exceptional, by an active transport mechanism. The unabsorbed minerals are excreted in the faeces [8]. For more detail, the reader is referred to chapters 3, 4 and 5.

Diet, Nutrition and Oral Health

Oral and systemic well-being is fundamentally linked with diet and nutrition. In this context, diet denotes the local actions of foods on oral tissues and includes the composition of the food, its consistency and the pattern and frequency of eating. In contrast, nutrition describes the systemic effects of nutrients on the development, regeneration and repair of tissues [21].

There is a synergistic multidirectional relationship between oral health and nutrition and diet.

Oral infectious diseases, as well as acute, chronic, and terminal systemic diseases with oral manifestations influence the ability to eat and consequently to achieve an adequate diet and attain nutrient balance. Equally, nutrition and diet can impact the development and status of the oral cavity as well as the progression of oral diseases. The impact of diet and nutrition on oral health is discussed in Part 3 and the impact of oral health on diet and nutrition in Part 4.

Nutrition influences the teeth primarily during their formation; whereas bone and the soft tissues of the mouth respond promptly to nutritional imbalance, as they are continuously being renewed [21]. At the pre-eruptive stage, deficiencies of energy, protein, calcium, phosphorus, iodine, iron and vitamins A, C, and D can affect tooth development. Diet and intake of nutrients continue to influence tooth development and mineralisation after tooth eruption. In addition, due to the rapid rate of tissue turnover of the oral mucosa, deficiencies of some nutrients such as vitamins B_2, B_{12}, C and folate as well as iron and zinc may initially be reflected in the mouth.

Primary dietary factors and eating patterns associated with dental caries risk include the form of the food (e.g. solid, liquid), the frequency of consumption of fermentable foods such as sugars/starch-based diets and the duration of exposure of the teeth to these fermentable products. On the other hand, dental caries, tooth loss (edentulism) and removable prostheses (dentures) can have a major impact on dietary habits and the composition of the diet, thereby impacting the general health and quality of life of the affected individuals. An inability to chew certain foods, such as steak, whole grains, fruit and vegetables, due to untreated painful dental caries and tooth loss may lead to inadequate intake of protein, dietary fibre, vitamins and minerals [22].

Dental erosion is associated with acids of intrinsic (gastrointestinal) and extrinsic (dietary and environmental) origin. Acidic foods may contain one or more of: acetic, ascorbic, carbonic, citric, malic, oxalic, phosphoric and tartaric acids. An important factor influencing the erosive potential of acidic foods and drinks is eating habits, such as the length of time that an acidic drink remains in the mouth (e.g. swishing the drink around the mouth, nighttime bottle feeding). Individuals with a healthier lifestyle that includes diets high in acidic fruits and vegetables may have higher incidences of dental erosion [23]. Consumption of soft drinks and chewing vitamin C tablets have been reported to be significantly associated with development of dental erosion with approximately 2.4 and 1.2 fold increased risk, respectively [24]. On the other hand, milk and yogurt provide important sources of dietary calcium, phosphate and casein which are known to protect enamel [24]. The relationship between diet and dental erosion is considered in Chapter 9.

Periodontal disease is not initiated by poor nutrition; however susceptibility to the disease may increase as a result of deficiencies in vitamin C, folate and zinc, as these nutrients increase the permeability of the gingival barrier at the gingival sulcus. Other nutrients such as calcium, phosphate, vitamin A, vitamin E and β-carotene are also reported to maintain gingival and immune system integrity. Due to the anti-inflammatory properties of omega-3 polyunsaturated fatty acids, they may be useful to manage periodontitis [25]. As part of a periodontal prevention and treatment regime, reducing consumption of refined sugars and increasing consumption of fish oils, fibre, fruit and vegetables are recommended by the 2011 European Workshop on Periodontology [26].

Diet, after tobacco and alcohol, has been recognised as an important risk factor for oral cancer; although the relationship between oral cancer and diet is complex. Consumption of cereals, dairy products, olive oil and raw fruit and vegetables, independent of tobacco and alcohol use, as well as ingestion of some micronutrients such as riboflavin, selenium, magnesium, and iron have been reported to be inversely associated with the risk of oral cancer [27]. A 50% reduction in the risk of oral cancer with daily fruit and vegetable consumption has also been suggested following a systematic review [28].

Oral manifestation of some acute diseases (e.g. head and neck cancer, infections) and chronic diseases (e.g. diabetes, HIV AIDS) may have a profound effect on the diet and the nutritional status of individuals. HIV is associated with some oral manifestations such as viral/fungal infections, stomatitis, xerostomia, periodontal disease and Kaposi’s sarcoma. Burning mouth syndrome, periodontal disease, candidiasis, dental caries and xerostomia are oral manifestations of uncontrolled diabetes. All these conditions affect eating ability, limiting the intake of nutrients and consequently compromise the nutrition status of individuals.

Table 1. Terms of reference values for food energy and nutrients for groups of people in Australia, the UK, and the USA.

Country	General Term	Covered terms relating to energy and nutrient intakes
Australia	Nutrient Reference Value (NRV)[i]	Estimated Average Requirement (EAR), Recommended Dietary Intake (RDI), Adequate Intake (AI), Estimated Energy Requirement (EER), Upper Level of Intake (UL)
UK	Dietary Reference Value (DRV)[ii]	Estimated Average Requirement (EAR), Lower Reference Nutrient Intake (LRNI), Reference Nutrient Intake (RNI), Safe intake
USA	Dietary Reference Intake (DRI)[iii]	Recommended Dietary Allowance (RDA), Adequate Intake (AI), Tolerable Upper Intake Level (UL)

Footnotes:

i) Australian Definitions [3]:
EAR: A daily nutrient level estimated to meet the requirements of half the healthy individuals in a particular life stage and gender group.
RDI: The average daily dietary intake level that is sufficient to meet the nutrient requirements of nearly all (97–98 per cent) healthy individuals in a particular life stage and gender group.
AI (used when an RDI cannot be determined): The average daily nutrient intake level based on observed or experimentally-determined approximations or estimates of nutrient intake by a group (or groups) of apparently healthy people that are assumed to be adequate.
EER: The average dietary energy intake that is predicted to maintain energy balance in a healthy adult of defined age, gender, weight, height and level of physical activity, consistent with good health. In children and pregnant and lactating women, the EER is taken to include the needs associated with the deposition of tissues or the secretion of milk at rates consistent with good health.
UL: The highest average daily nutrient intake level likely to pose no adverse health effects to almost all individuals in the general population. As intake increases above the UL, the potential risk of adverse effects increases.
ii) UK Definitions [4, 5]:
EAR: An estimate of the average requirement of energy or a nutrient needed by a group of people (i.e. approximately 50% of people will require less, and 50% will require more).
RNI: The amount of a nutrient that is enough to ensure that the needs of nearly all a group (97.5%) are being met.
LRNI: The amount of a nutrient that is enough for only a small number of people in a group who have low requirements (2.5%) i.e. the majority need more.
Safe Intake (used where there is insufficient evidence to set an EAR, RNI or LRNI): The amount judged to be enough for almost everyone, but below a level that could have undesirable effects.
iii) USA Definitions [6]:
RDA: Average daily level of intake sufficient to meet the nutrient requirements of nearly all (97%-98%) healthy people.
AI: Established when evidence is insufficient to develop an RDA and is set at a level assumed to ensure nutritional adequacy.
UL: Maximum daily intake unlikely to cause adverse health effects.

Table 2. Vitamins – key information

	Vitamin	Physiologic Functions	Dietary sources
Fat-soluble vitamins	Vitamin A β-carotene (Vit A precursor)	• Necessary for visual pigmentations • Required for cell differentiation, gene regulation, reproduction, bone health, immune function • Essential for bone and tooth growth	Vit A: animal products β-carotene: carrots, sweet potatoes, other red-orange vegetables
	Vitamin D	• Needed for calcium balance/homoeostasis and bone health • Needed for cell differentiation and immune system	Mushrooms, dairy milk & fortified non-dairy milk, fortified cereals, cod liver oil, tuna, salmon, egg yolks
	Vitamin E	• Membrane antioxidant • Heart health • Protects cell walls	Seeds and nuts, vegetable oil
	Vitamin K	• Necessary for blood clotting • Required for calcium metabolism and bone health	Green leafy vegetables, produced by bacteria in the large intestine
Water-soluble vitamins	Vitamin B_1 (Thiamin)	• Cofactor for oxidative decarboxylation both in the Kreb's Cycle and in converting pyruvate to acetyl-CoA • Needed for normal muscle function, including the heart muscle. • Involved in oxidative carboxylation reactions, which also require manganese ions. • Important to nerve function	Whole grains, dried beans, peas, peanuts, animal proteins
	Vitamin B_2 (Riboflavin)	• Supports the release of energy from foods, as a cofactor in the mitochondrial respiratory chain • Precursor of flavin adenine dinucleotide (FAD) and flavin mononucleotide (FMN), which are coenzymes used to oxidise substrates	Whole grains, green and yellow vegetables, animal proteins
	Vitamin B_3 (Niacin)	• As a cofactor in the mitochondrial respiratory chain, helps in the release of energy from foods. • Transformed into nicotinamide adenine dinucleotide (NAD) and nicotinamide adenine dinucleotide phosphate (NADP), which play a key role in oxidation-reduction reactions in all cells.	Lean meats, fish, poultry, whole grains, corn, sweet potatoes.
	Vitamin B_6	• Helps in the release of energy from foods. • Used as a cofactor by nearly 100 enzymatic reactions, mainly in protein and amino acid metabolism. • necessary for healthy immune and nervous systems	Potatoes, chickpeas, yeast, nuts, bulgur wheat, fish, rice, bananas

	Vitamin B_{12}	• Essential for metabolism of fats and carbohydrates • Synthesis of proteins and new cells, especially red blood cells • Activates folates	Fortified cereals, nutritional yeast, algae, animal products
	Biotin	• As a cofactor, involved in metabolism of fatty acids, amino acids and utilization of B vitamins.	Peanuts, almonds, soy protein, eggs, yogurt, sweet potatoes
	Vitamin C	• Needed for synthesis of carnitine (transports long-chain fatty acids into mitochondria) and the catecholamines, adrenaline and noradrenaline. • Assists transport and uptake of non-haem iron at the mucosa, the reduction of folic acid intermediates, and the synthesis of cortisol. • Potent antioxidant. • Formation of collagen	Citrus fruits, cabbage, berries, peppers
	Folic acid	• As a family of cofactors that carry one-carbon (C1) units required for the synthesis of thymidylate, purines and methionine • Essential for metabolic pathways involving cell growth, replication, survival of cells • Essential for DNA and red blood cell formation.	Dark green leafy vegetables, yeast, wheat germ
	Panthothenic acid	• Plays an essential role in the Krebs cycle. • Component of coenzyme A.	Fortified cereals, mushrooms, rice, sweet corn

Table 3. Daily requirements of specific elements

Mineral / element	RDA (plain) or AI (*Italic*)[1,*]	RNI (plain) or Safe intake (*Italic*)[2, *]	Daily dietary intake [3]
Major minerals /macro minerals/ macro elements			
Calcium	400-1200 mg	525-1000 mg	
Phosphorus	300-1200 mg	270-775 mg	
Potassium	-	700-3500 mg	
Sodium	-	210-1600 mg	
Chloride	-	320-2500 mg	
Trace elements /micro minerals/ micro elements (including Ultratrace elements)			
Magnesium	40-400 mg	55-300 mg	
Iron	6-15 mg	1.7-14.8 mg	
Zinc	5-15 mg	4-9.5 mg	
Fluoride	*0.1-4.0 mg*	*Infants: 50 µg/kg bw*	
Copper	*0.4-3.0 mg*	0.2-1.2 mg	
Selenium	10-70 µg	10-75 µg	
Iodine	40-150 µg	50-140 µg	
Manganese	*0.3-5.0 mg*	*Adults: 1.4 mg* *Infants/Children: 16 µg*	
Molybdenum	*15-250 µg*	*Adults: 50-400 µg* *Infants/Children: 0.5-1.5 µg/kg bw*	
Chromium	*10-200 µg*	*Adults: 25 µg* *Infants/Children: 0.1-1.0 µg/kg bw*	25–50 µg
Cobalt		*1.4 mg* [4]	
Tin		*1–40 mg*	
Vanadium		*10–30 µg*	
Trace elements with no current RDA or RNI			
Aluminium			2-10 mg
Arsenic			30 µg
Boron			0.5–3.5 mg
Bromine			2–8 mg
Cadmium			10–20 µg
Germanium			0.4–3.4 mg
Lithium			200–600 µg
Nickel			70–260 µg
Rubidium			1–5 mg µg
Silicon			20–50 mg

* The lower end of the range is for infants and the upper end of the range is for adults.

[1] Ref [29]; [2] Ref [5]; [3] Ref [30]; [4] Ref [5, 31] – note: although cobalt is an element, it is utilised only in the form of vitamin B_{12} and therefore usually discussed in that context.

Figure 1. Eatwell Guide of Public Health England [1]

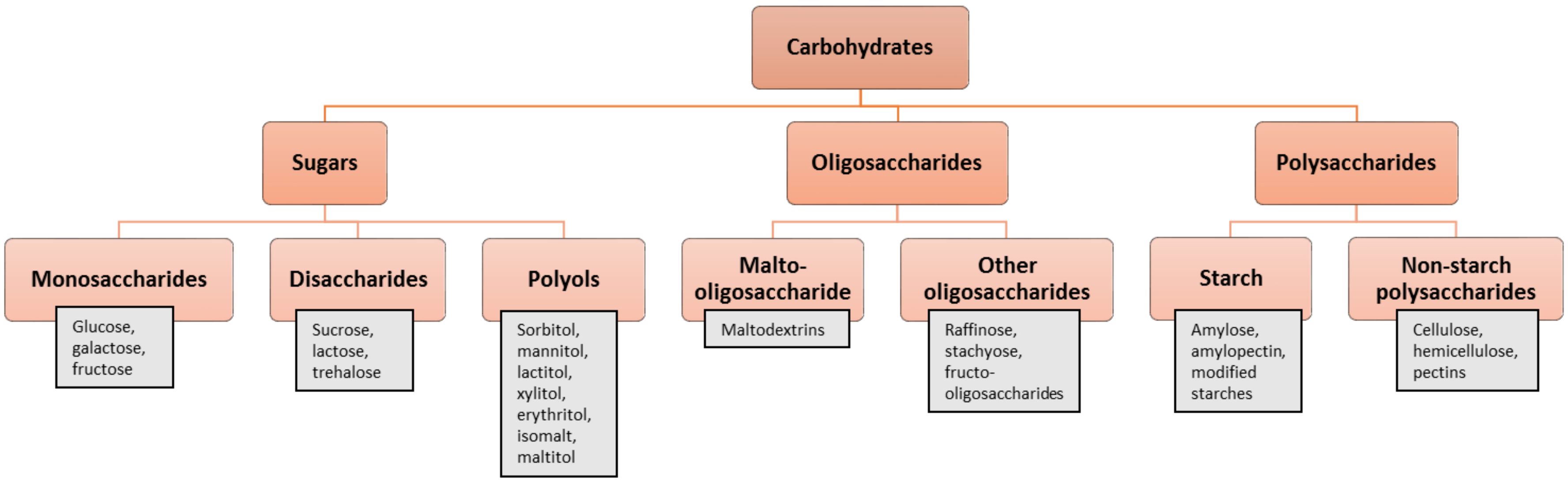

Figure 2. Major dietary carbohydrates.

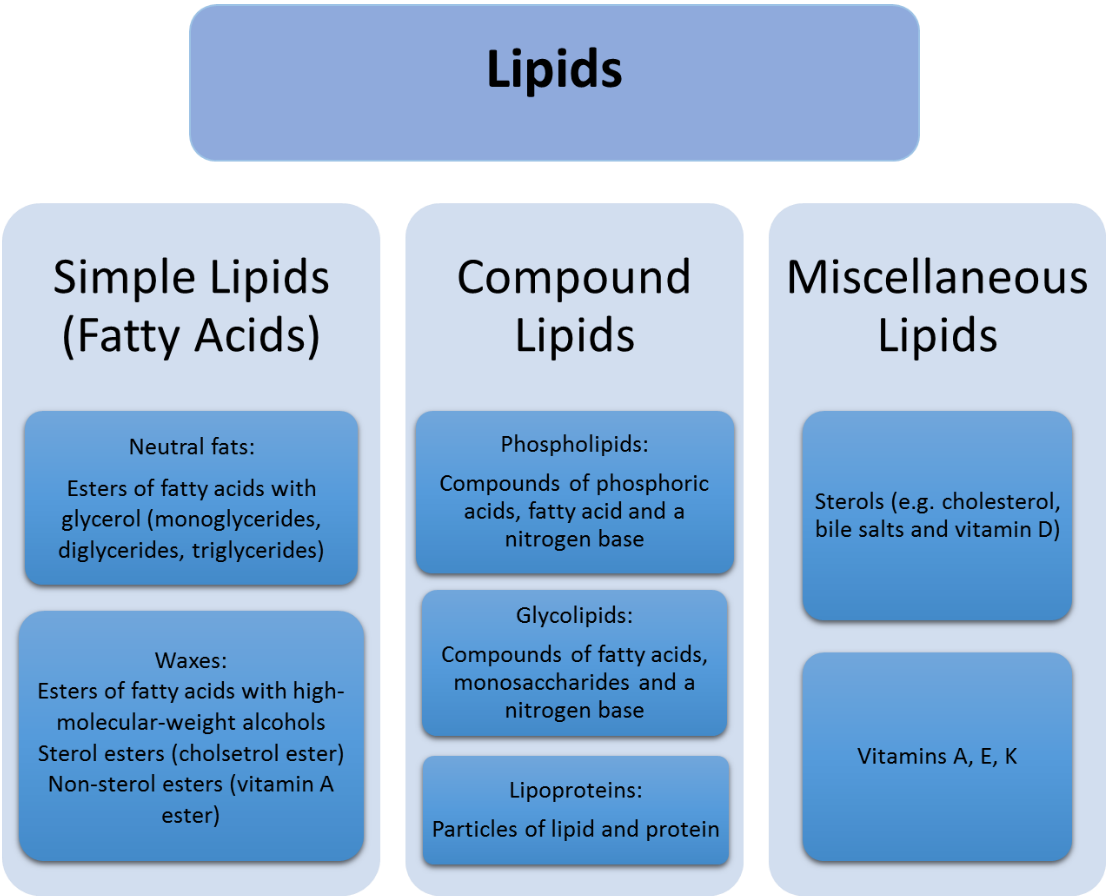

Figure 3. Classification of Lipids, Ref [8]

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