Macronutrients, minerals, vitamins and energy

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Abstract

Carbohydrates have the general formula $C_n(H_2O)_n$. Monosaccharides have between three and six carbon atoms and exist as chains or ring structures. As rings, they link with other monosaccharide rings. The major carbohydrate in humans is glucose, which is stored as glycogen: branching chains of glucose molecules. Fat (triglyceride), which makes up adipose tissue, consists of three fatty acids bonded to glycerol, but other lipids include phospholipids and steroids. Proteins are composed of chains of amino acids linked by amide bonds folded on each other to form protein structures. Vitamins and minerals are obtained from the diet and are required in varying quantities for a variety of metabolic processes. Energy is derived from the oxidation of carbohydrate, fat and protein. Energy expenditure and substrate oxidation can be calculated from oxygen consumption, carbon dioxide production and urinary nitrogen excretion.

Keywords Carbohydrate, fat and protein; energy expenditure and substrate oxidation; glycogen and triglycerides; monosaccharides; vitamins and minerals

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Learning objectives

After reading this article, you should be able to:
- understand the structures of the three macronutrients - carbohydrate, fat and protein
- understand the place of these macromolecules in the structure of the body as well as the role of vitamins and minerals in metabolism
- understand the way the macronutrients are ingested and oxidized to produce energy that the body uses for metabolism, for external work and for thermoregulation

Macronutrients

Carbohydrate, fat and protein make up most of the body's soft tissue structure. These complex molecules are also the form in which protein and energy are ingested (macronutrients). What allows their formation is the ability of the carbon atom to form four bonds at once. In simple terms, carbohydrate, usually in the form of glucose (or glycogen), is the energy substrate for immediate use, fat in the form of adipose tissue represents the long-term energy store, and proteins form the 'living' tissue. Carbohydrate, in combination with protein (glycoproteins) and with fat (glycolipids), is also important in the structure of membrane receptors for hormones and other transmitter molecules, and fat is a major structural component of cell membranes. In this article the structure of carbohydrate, fat and protein and their role in the provision of energy are discussed; their metabolic interrelationships are described on page 2 of Intermediary Metabolism.

Carbohydrates

Carbohydrates are classified in three broad groups – monosaccharides, disaccharides and polysaccharides. They have the general molecular formula $C_n(H_2O)_n$ (where n denotes the number of carbon atoms, with an H and an OH group attached to each carbon [Figure 1]). Monosaccharides may have three (triose), four (tetrose), five (pentose) or six (hexose) carbons. Triose sugars (e.g. glyceraldehyde) are important in intermediary metabolism, such as glycolysis, and pentoses in the pentose shunt, but it is the hexose sugar (glucose) that is the basic unit of carbohydrate storage and energy provision.

Glucose can exist in a straight chain form or as a ring (Figure 1); the aldehyde group on C1 reacts with the hydroxyl group on C5 to form a stable covalent bond and gives rise to a six-member ring (Figure 1). In solution, the two forms are in equilibrium but the ring structure predominates. Conventionally, glucose is seen as a flat structure at right angles to the plane of the page with hydrogen atoms and hydroxyl groups above and below the plane of the ring (Figure 1). Pentoses (e.g. ribose and deoxyribose in nucleic acids) form five-member rings as do some hexoses (e.g. fructose). The presence of an asymmetrical distribution of atoms or groups around the carbon atoms allows the formation of isomers. In glucose, the biologically important ones arise from the disposition of the H and OH groups around C5 and C1. The asymmetry around C5 denotes the D or L forms, dependent on the rotatory effect they have on polarized light. Most of the glucose in animals is in the D configuration (hence the term dextrose, commonly used for glucose) and the enzymes responsible for its metabolism are specific for this configuration. The isomerism of H and OH around C1 (α or β) is important in the formation of bonds between glucose units (see below). Two monosaccharides can combine to form a disaccharide – maltose from two glucose units, lactose from glucose and galactose and sucrose from glucose and fructose. Glucose units can join at C1 and C4 to form chains or at C1 and C6 to form branching molecules (Figure 1). Starch is the principal carbohydrate store in plants and is made up of a mixture of non-branching chains of α D-glucose (amylose) and branched chains of 24–30 glucose molecules, the branching occurring at the 1:6 linkage. Glycogen is the carbohydrate store in the animal body (animal starch). It is found predominantly in muscle and liver and has a similar composition to starch but is a much more highly branched structure (Figure 1) of variable, and even indeterminate, molecular weight. Cellulose found in plants is also made up of glucose units and these are also linked at C1 and C4. The glucose making up cellulose is the β isomer of C1 (see above) and animals do not have an enzyme to break this linkage; cellulose is therefore indigestible by enzymes, though it is broken down by fermentation.

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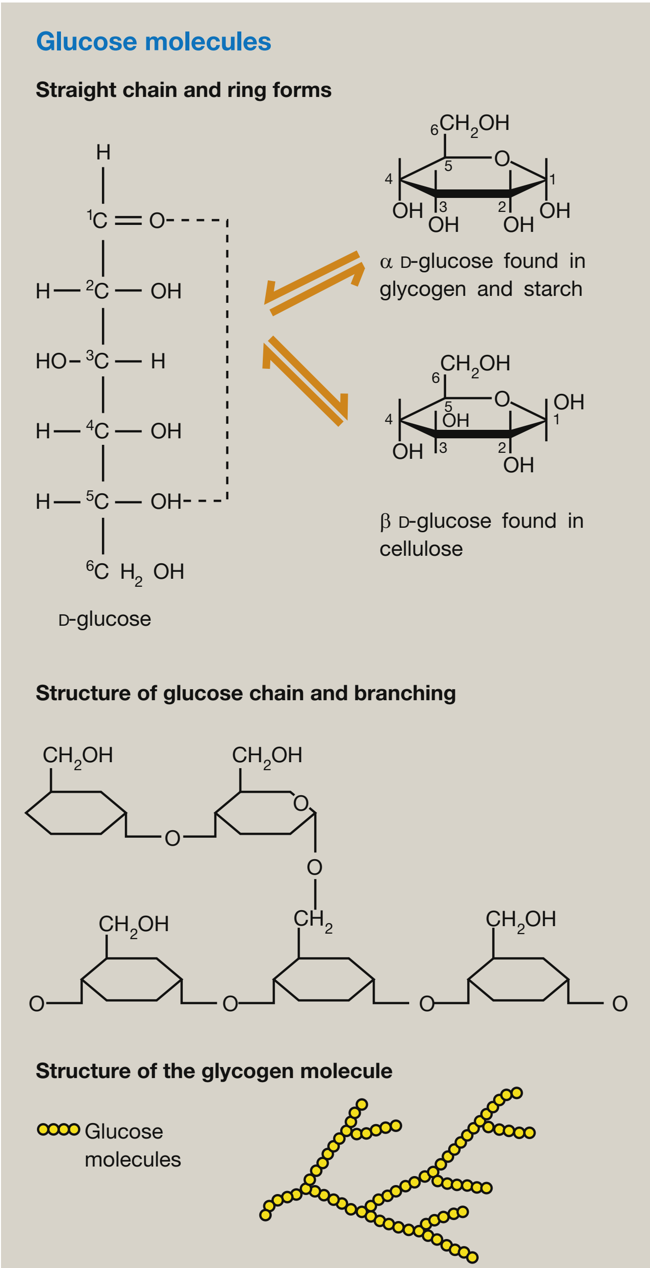

Figure 1

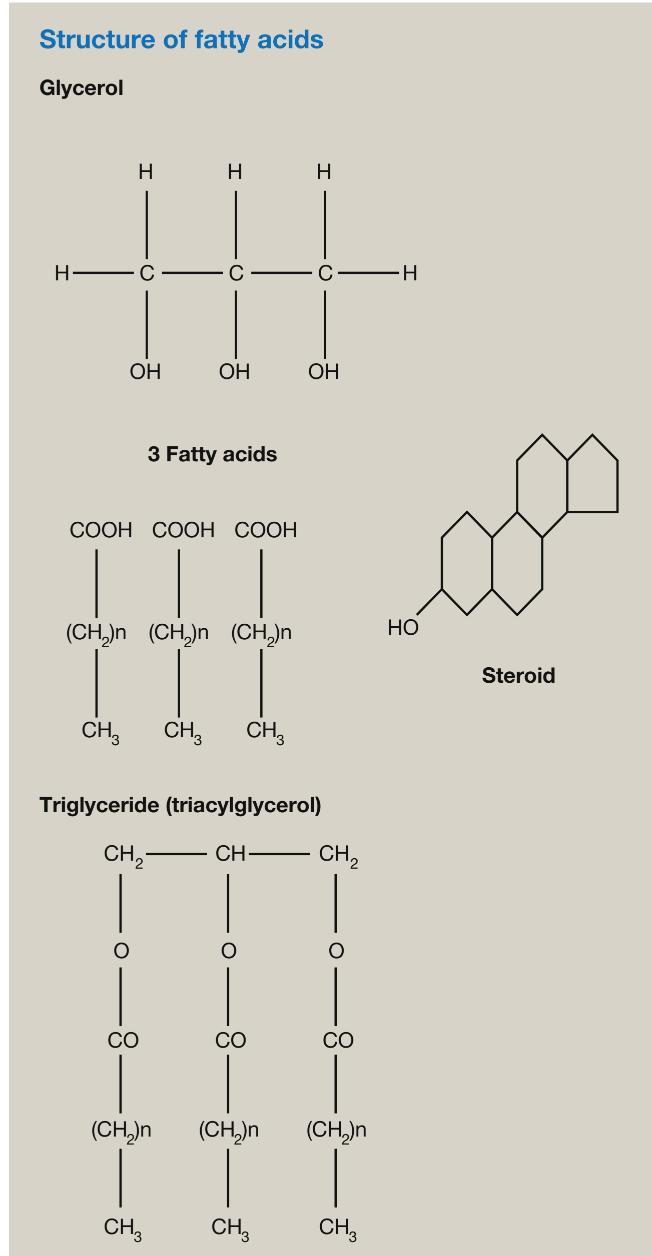

Figure 2

Fats

Fats (lipids) differ from other macronutrients in that they are poorly soluble in water, but highly soluble in organic solvents such as ether or acetone. Like carbohydrates they are composed of carbon, hydrogen and oxygen (Figure 2), but the proportion of oxygen atoms to carbon and hydrogen is lower than in carbohydrate.

Fatty acids are chains of carbon atoms to which hydrogen atoms are attached with a carboxyl group (COOH) at one end. The carbon atoms are lipophilic and the COOH group hydrophilic. Two of the most common fatty acids in animal cells are palmitic (16C chain) and stearic (18C) acid. Fatty acids are distinguished from one another by the number of carbon atoms in the chains and the number of double bonds. When only single bonds exist the acid is said to be saturated; palmitic and stearic acids are both saturated acids. With one or more double bonds (C=C), the fatty acid is said to be unsaturated. Fatty acids are classified into families according to the position of their first double bond, counting from the non-carboxyl end of the fatty acid molecule. The terms n-3 (or omega-3), n-6 or n-9 denote the three main families. Unsaturated fatty acids include oleic (n-9; one double bond), linoleic (n-6; two double bonds) and arachidonic acids (n-6) that contain four double bonds. Arachidonic acid is an intermediary metabolite in the synthesis of prostaglandins, a group of substances that have a wide range of physiological effects. Some dietary n-3 fatty acids (e.g. eicosapentaenoic acid found in fish oil) have come to prominence for their ability to dampen down

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