3. Carbohydrate metabolism and activity

Introduction: Nutritional Ingredients

The primary nutrients are used by the organism in a variety of ways. Their breakdown in the digestion results in metabolites that can be utilized for further metabolic processes in the organism. They can be used for the formation of large compounds that contribute to the structure of the organism (like the carbohydrates in the cell wall of plants, proteins in collagen, or the lipids in membranes). The metabolites can also be converted to substances that regulate the organism and its functions (as for instance in immune recognition, neurotransmission, or as enzymes). And they can be oxidized further to provide energy for the above processes and bio-mechanical and active transport needs through their ultimate breakdown, as happens for instance with glucose.

Carbohydrates, proteins, and lipids can each be used for a variety of different functions; within limits they can also be converted one into the other with the help of intermediates in the citric acid cycle, which interconnects their anabolic/catabolic cycles. And they each have an area of characteristic activity, which will be discussed in the following chapters for the respective compounds. This chapter deals with carbohydrate metabolism and function, chapter 4 discusses protein metabolism and activity and chapter 5 the metabolism and activity of the lipids.

3.1. Carbohydrates and water

In section 1.2.4 we found how the breakdown of water stands at the beginning of the synthesis of carbohydrates in photosynthesis. This is one important process that shows the relationship between carbohydrates and water. Water is oxidized to convert sunlight into biochemical energy for the synthesis of carbohydrates from CO_2:

$$6\ CO_2 + 6\ H_2O + \text{light}\ (\ C_6\ H_{12}\ O_6\ \text{(carbohydrates)} + 6\ O_2$$

Animals and humans breathe in the O_2 and use it to break down carbohydrates to CO_2 and water in the citric acid cycle and oxidative phosphorylation (section 1.2.2.). This oxidative catabolic process, together with the reductive anabolic process of photosynthesis, forms a cycle in nature between plants and the organisms of animals and human beings (see fig. 1.3) in which water is alternately oxidized and formed.

The water/carbohydrate connection is also found when sugar is burnt without the addition of oxygen, i.e. made into carbon. This happens when sugar is heated up in a closed container so that no oxygen can enter. The result will be carbon and water, the latter escaping as steam. This phenomenon would imply that the general formula for carbohydrate monomers could be written as $C_n\ (H_2O)_n$. This is the reason they were originally given the name *carbo-hydrate*. The general formula for glucose for instance is $C_6\ H_{12}\ O_6$.

Carbohydrates have a relation to water both in their structure and in their metabolic processes. In the formation of polysaccharides, as in forming the peptide bonds in proteins, one water molecule is released from glucose in forming the glycosidic bond with every addition of a glucose molecule.

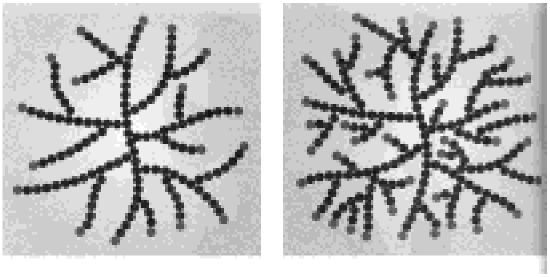
3.2. Functions of carbohydrate polymers

Carbohydrate polymers, like all large compounds, hold within their structure *potential energy* that becomes available at their breakdown as metabolic and other energy for the organism. Many common carbohydrates are polysaccharides.

Polysaccharides are polymers of sugars (see section 2.1.1.). The most commonly occurring monomer is glucose (section 3.3.). Carbohydrates also have structural functions.

Storage function

Glycogen and starch are storage forms for glucose. Glycogen is usually more branched than starch, which allows for the glucose to be cleaved off at more points at the same time. Therefore glycogen, which is the main glucose polymer in higher organisms, can give a greater rate of supply of glucose in demand situations than starch, which exists in plants only, would be able to. Animals and humans have more glucose quicker at their demand than plants. As mentioned before in section 2.1.1. glycogen does not occur in heart and brain cells. It occurs mainly in liver and muscle cells, but only the liver can convert lactate to glucose. Muscle cells are dependent on the liver for gluconeogenesis (see the Cori cycle, section 1.2.1.) and the serum glucose level is primarily buffered by the liver. *The liver's carbohydrate function is prototypical in higher animals and humans*.



Amylopectin **Glycogen**
(Campbell, 1999)

Glycogen has no structural support function in higher organisms and therefore can be broken down without affecting their structure. Glycogen stores in the liver form an ideal energy supply for the organism. However, human glycogen stores are estimated to be depleted after 10-15 hours of fasting and therefore need constant replenishing.

Structural function

Cellulose is a structural glucose polymer in plants (see fig. 2.2.). Structural carbohydrates in non-plants have amino acids or contain amino acid sequences as monomers to form chitin or peptidoglycans (section 2.1.1.). The breakdown of cellulose does affect the structure of the plant, as does the breakdown of peptidoglycans by antibiotics affect the structure of bacteria, and the breakdown of chitin affects the structure of invertebrates that carry it in their exoskeleton.

Glucose cannot be cleaved off of cellulose without the presence of special enzymes called cellulases, which are found in bacteria and in the digestive tract of, for instance, cattle. Humans do not have cellulases in their digestive tract. Cellulose is the main insoluble part of dietary fiber (bulk or roughage) in our diet, which stimulates peristalsis and binds some of the potentially toxic substances in food.

3.3. Glucose and Energy

Glucose is the most abundant of the carbohydrate monomers in nature. Glucose metabolism is central to the energy supply of living organisms. It can be transported in the body to the place where energy is required.

Anaerobic breakdown of glucose in glycolysis yields pyruvate or, under lasting anaerobic conditions, lactate and 2 molecules of ATP per glucose molecule. Its further aerobic breakdown occurs in the citric acid cycle (section 1.2.3.), which can yield 30 more ATP molecules. The catabolism of glucose releases energy, which results in the phosphorylation of ADP to ATP. ATP is the carrier of immediate energy for organisms. It contains two phosphoanhydride bonds linking the phosphates. These bonds hydrolyze easily, with a consequent immediate release of the energy (less than 1 minute). As such, it is directly available biochemical energy, which must, however, be used “right away”. It can be used to convert the biochemical energy to bio-mechanical energy (as in the case of the exercising muscle), bio-electrical energy (as in the nervous system), light (as in phosphorescent bacteria), active transport, etc.

The freed up energy from glycolysis and oxidation in the citric acid cycle can also be used in the form of ATP for reductive anabolic processes that result in compounds such as proteins and lipids. Glucose is a reducing sugar. When glucose is oxidized, another compound can be reduced in an anabolic reaction with the energy that becomes available (transferred via ATP).

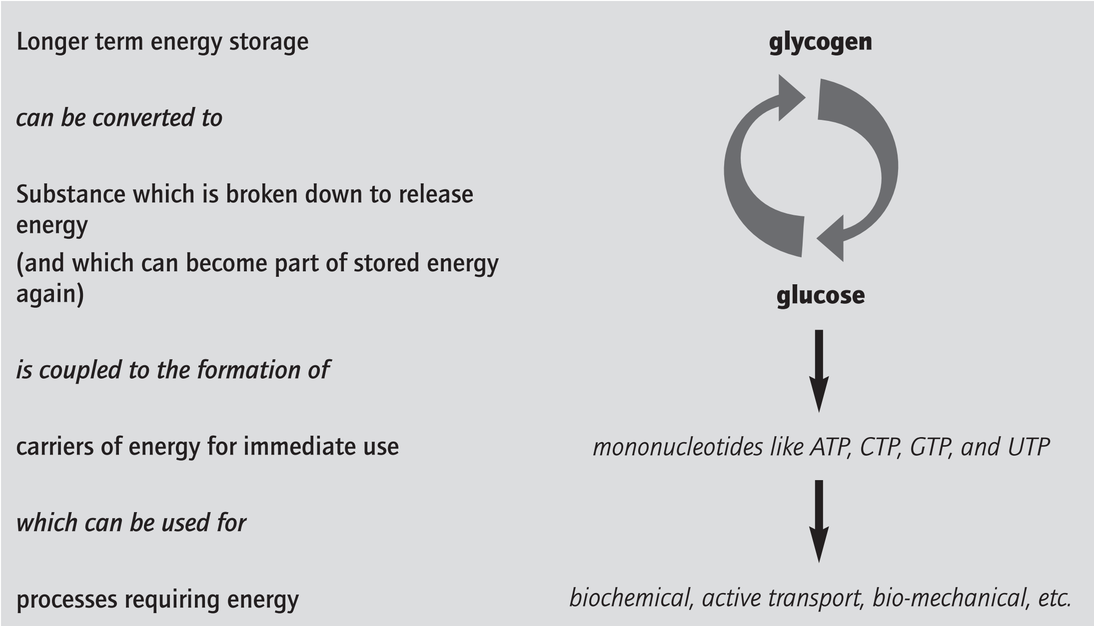


Fig. 3.1 The conversion of energy-carrying compounds to energy-requiring processes

Since it is not needed in the structures of the organism, glucose and glycogen can be broken down without consequences for the structure of the body. Thus glucose becomes the main supplier of energy for living organisms. *The prototypical function of glucose in organisms is to provide energy.*

3.4. Summary and conclusion

Carbohydrate functions

Carbohydrates can be used for a variety of functions in organisms. They serve different functions in plants than in higher organisms. Plants are the only organisms that use homopolysaccharides to build up their structural components, as well as using starch and glucose for an energy source. In lower animals carbohydrates can also have structural