Nutrient Metabolism of Vertebrate Animals

Chaozhi Zhang

Beijing Royal School, Beijing, 102209, China

Abstract. It is generally believed that all animals in the world mainly are composed of C, H, O and N elements, which are used in the process of nutrient metabolism, including protein, carbohydrate and lipid metabolism. Although most metabolic procedures are common among different vertebrates, some processes like nitrogen metabolism are different. Here, we briefly review the metabolic procedures of three nutrients and discuss some diversified metabolic pathways. At last, we discussed the linkage between these substances, hoping to gain a better understanding.

Keywords: Carbohydrate; Protein; Lipid; Metabolism; Biochemistry.

1. Introduction

There are many kinds of organisms on the earth, and life phenomena are complicated. Therefore, it is difficult to give an exact definition of life. However, compared with non-living organisms, living organisms have significant common characteristics, one of which is the identity in chemical composition: all organisms have roughly the same elemental composition and molecular composition. The most abundant elements in living organisms are H, O, C and N, which are very light elements, which means they are easy to use common electron pairs to form 1,2,3 and 4 covalent bonds, respectively. Single or double bonds can be formed between them, thus forming various organic compounds as basic components of living organisms. Many biological macromolecules (such as proteins, polysaccharides, nucleic acids) are high relative molecular weight polymers, which are polymerized from small, relatively simple organic compounds. Although lipids are not biological macromolecules, a large number of lipid molecules can be combined into large aggregates, biofilms, by non-covalent bonds.

Here, we briefly summarize the chemical components, main metabolic pathways and their interrelationships of the three major nutrients, in order to gain a better insight about nutrients metabolism.

2. Carbohydrate Metabolism

2.1 Chemical Composition

Most Carbohydrates consist of only three elements: carbon, hydrogen, and oxygen. The chemical formula is (CH2O) n or Cn (H2O) m. Among them, the atomic number ratio of H and O is 2:1, which is like water molecules. Therefore, it was mistaken that this kind of material is a carbon hydrate, and the carbohydrate is also named.

Carbohydrates are defined from the chemical nature: carbohydrates are polyhydroxyaldehyde, polyhydroxyketone or their derivatives, or polymers that can produce these compounds when hydrolyzed. According to their degree of polymerization, they can be divided into: 1. Monosaccharides: sugars that cannot be hydrolyzed into smaller molecules, such as glucose and fructose (Fig.1, 2), which are pentahydroxyhexanal and pentahydroxyhexanone, respectively. The chemical formula is often written as (CH2O)n; 2. Oligosaccharides: including disaccharides, trisaccharides and tetrasaccharides; 3. Polysaccharides: Sugars that produce more than 20 monosaccharide molecules during hydrolysis, such as starch(Fig.3) and cellulose, which are condensed from multiple glucose molecules.

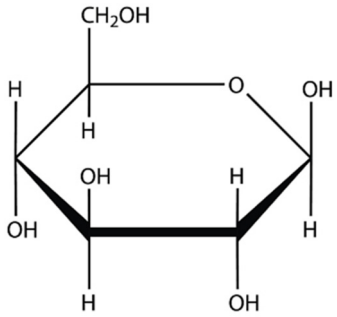


Figure 1. Glucose

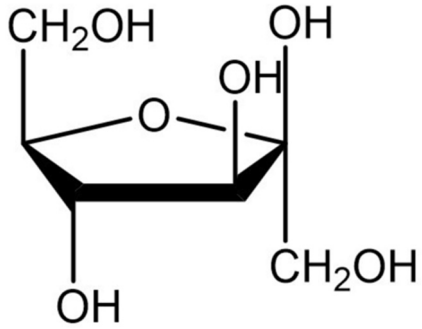


Figure 2. Fructose

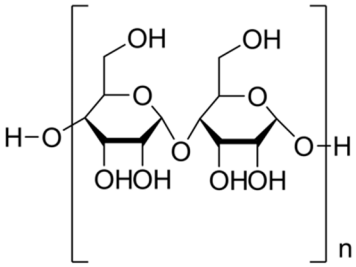


Figure 3. Starch

2.2 Source of Carbohydrate

Carbohydrate in animals is mainly absorbed through the digestive tract, followed by gluconeogenesis, where non-sugar substances such as glycerol, lactic acid, propionic acid, and glucogenic amino acids are converted in the liver and kidneys.

For non-ruminant animals, the main source of sugar is starch in the digestive tract by enzymatic hydrolysis into glucose, and then absorbed through the small intestine. For ruminants, the sugar intake from feed is mainly cellulose, which can be converted into low-grade fatty acids such as acetic acid, propionic acid and butyric acid under the action of cellulase secreted by microorganisms in the rumen. Propionic acid is the main precursor of glucose.

2.3 Glucose Catabolism

Glucose catabolism includes aerobic oxidation pathway, glycolysis pathway and pentose phosphate pathway.

2.3.1 Aerobic Oxidation Pathway

The aerobic oxidation pathway refers to the process by which glucose is completely oxidized under aerobic conditions to produce water and carbon dioxide. It is the main way of sugar decomposition, through which most cells obtain energy.

The main processes include: 1. In the cytoplasm, glucose is converted to pyruvate; 2. pyruvate into the mitochondria, under the catalysis of pyruvate dehydrogenase complex, produce acetyl coenzyme A; 3. Acetyl-CoA in mitochondria was decomposed into carbon dioxide and H_2O by tricarboxylic acid cycle oxidation, and generated NADH, FADH2 and ATP. The total reaction of glucose aerobic decomposition is: $C_6H_{12}O_6+6O_2+30ADP+30Pi \rightarrow 6H_2O+6CO_2+30ATP$

2.3.2 Glycolysis Pathway

It refers to the process in which glucose generates lactic acid and releases energy in the absence of oxygen, which can quickly provide the energy required for physiological activities during hypoxia or exercise.

The process is carried out in the cytoplasm and is divided into two stages: 1. Glucose is decomposed into pyruvate; 2. Pyruvic acid is reduced to lactic acid under the action of lactate dehydrogenase. The whole process involves three key enzymes: hexokinase, phosphofructokinase

and pyruvate kinase. The total reaction of glucose anaerobic decomposition is: $C_6H_{12}O_6$+2ADP+2Pi →CH_3CH (OH) COO^-+2ATP

2.3.3 Pentose Phosphate Pathway

The intermediate product of pentose phosphate pathway is an important hydrogen donor for biosynthetic reaction, which provides hydrogen for the synthesis of fat, cholesterol and so on. Therefore, this pathway is more active in adipose tissue where lipid synthesis is vigorous.

The process is carried out in the cytoplasm, mainly including the oxidation reaction to produce NADPH and H^+; non-oxidative reaction produces ribose-5-phosphate. The total reaction is: 6-G-6-P+12$NADP^+$+7 H_2O→5G-6-P+6CO_2+12NADPH+12H^++Pi

3. Lipid Metabolism

3.1 Chemical Composition

Lipids are a class of bioorganic molecules with low solubility in water and high solubility in non-polar solvents. The chemical nature of most lipids is esters and their derivatives formed by fatty acids and alcohols. Lipid element composition is mainly C, H, O also contains some N, P, S. Lipids are a general term for fats and lipids. Fat is condensed from three hydroxyl groups of glycerol and three fatty acids, also known as triacylglycerol (Fig.4). Lipids mainly include phospholipids, glycolipids, cholesterol and its esters.

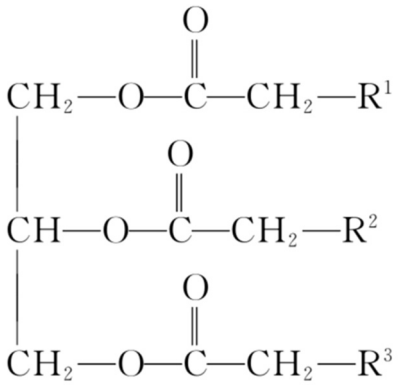


Figure 4. Triacylglycerol

3.2 Fat Synthesis

The synthesis of fatty acids is mainly carried out in the cytoplasm. After acetyl-CoA enters the cytoplasm, malonyl-CoA is synthesized under the action of acetyl-CoA carboxylase, and then the hydrocarbon chain of the acyl group is extended in units of two C atoms on the basis of acetyl-CoA through a cyclic reaction of condensation, reduction, dehydration, reduction and transfer.

The precursors of triglyceride synthesis are acyl-CoA and glycerol-3-phosphate. Fatty acid-CoA comes from the activation of fatty acids, glycerol-3-phosphate is formed by glycolysis intermediates, and the second is the phosphorylation of glycerol.

3.3 Fat Catabolism

Under the action of hormone-sensitive lipase, fat stored in fat cells is hydrolyzed into free fatty acids and glycerol and released into the blood, which is used by other tissues for oxidation.

Glycerol is transported to the liver and catalyzed by phosphoglycerate kinase to generate glycerol-3-phosphate, which is then dehydrogenated to dihydroxyacetone phosphate, which is then broken down into the glucose metabolic pathway.

Fatty acids are decomposed by β-oxidation. Fatty acids are transformed into acyl-CoA in the cytoplasm, and then into acetyl-CoA and acyl-CoA in the mitochondria with the help of acylcarnitine

transfer system. The process is repeated, and finally acetyl-CoA enters the tricarboxylic acid cycle for further oxidative decomposition.

4. Protein Metabolism

4.1 Chemical Composition

Protein mainly contains C, H, O, N and a small amount of S. Many proteins are composed of only amino acids, called simple proteins, but many contain chemical components other than amino acids. Such proteins are called conjugated proteins, such as glycoproteins.

There are only 20 common amino acids that make up proteins. Except for proline, these amino acids are structurally characterized by an amino group on the α-carbon atom adjacent to the carboxyl group, so they are called α-amino acids (Fig.5). There is also a hydrogen atom and a variable side chain attached to the α-carbon, called the R group. The difference between various amino acids is that the R group is different.

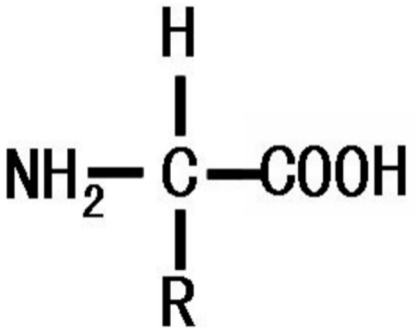


Figure 5. α-amino acids

Although there are only 20 kinds of amino acids that make up proteins, humans and other animals do not have the pathway to synthesize all amino acids in proteins. Therefore, amino acids that cannot be synthesized must be obtained from food, called essential amino acids. Amino acids that can be synthesized by themselves become nonessential amino acids.

4.2 Protein and Amino Acid Catabolism

Exogenous proteins enter the body and are degraded into small molecular amino acids through a series of digestion processes, and enter the liver and other tissues through the blood. The decomposition of amino acids is generally always the first to remove the amino, the formation of α-keto acid, which can be oxidized to form carbon dioxide and water, ATP, and can also be converted to sugar and fat.

In catabolism, once α-amino acid enters the liver, it is deaminated under the action of aminotransferase, which is transferred to α-ketoglutarate to form glutamic acid. The carbon skeleton after amino acid deamination enters the citric acid cycle for metabolism in different ways. Glutamic acid carries the amino group removed by many amino acids into the liver cells, which is transferred from the cytoplasmic sol into the mitochondria, where oxidative deamination occurs. The vast majority of terrestrial animals will take off the ammonia into urea excretion, birds and terrestrial reptiles, because of limited water in the body, their way of ammonia excretion is to form a solid uric acid suspension excreted, so birds and reptiles are also known as uriotelic animals.

5. Discussion

The metabolic activities of various substances in animal bodies are highly coordinated. Therefore, the metabolic pathways of substances are not isolated. Some common metabolic intermediates connect many pathways through branching points to form a complex metabolic network. In this network, the tricarboxylic acid cycle is at the center, which is not only the common destination of the

catabolism of sugars, lipids, amino acids and other substances, but also the hub of these substances interrelated and transformation.

Acetyl-CoA produced by oxidative decomposition of glucose is transferred from mitochondria to cytoplasm, then catalyzed by fatty acid synthase system to synthesize acyl-CoA, and synthesize triglyceride with α-glycerophosphate. In addition, acetyl CoA is also a raw material for the synthesis of cholesterol and its derivatives. In animals, the conversion of fat to glucose is limited, and fat is decomposed into glycerol and fatty acids, in which glycerol is converted into glucose or glycogen by gluconeogenesis.

The products of sugar catabolism, especially α-keto acids, can be transformed into non-essential amino acids that make up proteins through transamination or amination as a “carbon skeleton”. Most amino acids can be transformed into some intermediate products in the gluconeogenesis pathway through deamination, and then synthesize sugars and glycogen.

All amino acids can be converted to fat by acetyl CoA. The glycerol produced by the fats can be converted into skeletons for the synthesis of non-essential amino acids.

In summary, a deeper understanding of the three major nutrient metabolic pathways can enhance our understanding of the transformation of nutrients in the body.

References

[1] Garrett R H, Grisham C M. Biochemistry. 3rd ed.

[2] Horton H R, Moram L A. Ochs R S, Rawn J D, Scrimgeour K G. Principiles of Biochemistry. 3rd ed. London: Prentice Hall, 2002.

[3] Nelson D L, Cox M L. Lehninger Principles of Biochemistry. 3rd ed. New York: Worth Publisher, 2000.

[4] Voet D, Voet J G. Biochemistry. 3rd ed. New York: John Wiley& Sons, 2004.