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Article

Energy and life: Transfer and conversion of energy in muscle contraction

Ruoyu Xiao, Huiru Zhao, Lingfang Tang*

The Affiliated High School of Peking University, Beijing 100000, China
* Corresponding author: Lingfang Tang; tanglingfang@i.pkuschool.edu.cn

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Abstract: All living things on Earth need energy to support survival, movement, growth and repair. However, it is not very clear how energy functions in a specific life activity. In this paper, it will use human muscle contraction as an example to explain where energy comes from, how it flows into the human body, and how it is transferred and converted in human body to supply energy for muscle contraction. The whole process can be divided into transfer and conversion of energy. For energy transfer, energy from light can be captured directly by autotrophs in the biosphere and flows to heterotrophs through predation relationship. For energy conversion, the conversion between chemical energy, electrical energy and mechanical energy occurs during muscle contraction. This paper combines biology, chemistry and physics to show how the relationship between energy and life supports living activities from a multidisciplinary perspective, which will help people to have a deeper understanding for the relationship between energy flow and life.

Keywords: energy flow; life activity; energy transfer; energy conversion; muscle contraction

Introduction

Metabolism is the most basic trait of life, where energy metabolism refers to the transfer of energy between organisms and the external environment and the transformation conversion of energy within organisms. Life requires the support of energy, and energy supports life activities mainly through the transfer and conversion of energy. The typical life activities that reflect energy transformation in organisms are photosynthesis and respiration. Photosynthesis converts solar energy into chemical energy and stores it in autotroph's cells, while respiration releases stored chemical energy and converts it into other forms of energy for life activities. In fact, a complete life activity depends on more than photosynthesis and respiration to provide energy. This paper will explain an example of how energy is transferred and converted to supply energy for human muscle contraction, providing a reference for understanding the relationship between life activity and energy.

1. Energy transfer

The transfer of energy is an important part of energy supply, and energy pyramid can show us how energy is transferred in an ecosystem. The energy source of energy pyramid is mainly from solar energy. When energy is transferred from level to level in energy pyramid, only about 10% of the energy flows to the next level, and most of the rest energy is used by life activities or lost in the form of heat. The unidirectional flow of energy in an ecosystem is achieved through food chains or food webs [1].

2. Energy conversion

When energy is transferred to some living organism, energy needs to be transformed into different forms to support life activities. These different forms of energy mainly include solar energy, chemical energy, electrical energy, mechanical energy, etc. The following section will use muscle contraction as an example of life activity to introduce the mechanism of energy conversion in two parts: the types of energy required for muscle contraction; and the conversion process between different types of energy in muscle contraction.

2.1. Types of energy

2.1.1. Solar energy

Nuclear fusion occurs when protons of hydrogen atoms collide violently at the core of the sun and fuse to form helium atoms, and this process continues to release large amounts of energy. The energy from the sun is in the form of electromagnetic radiation (EMR). When sunlight, which is EMR from all the spectrum emitted by the sun, reaches the earth's surface, plants collect the sun's energy through light-absorbing pigment molecules, the most important of which is chlorophyll. It effectively absorbs blue-violet and red light, and reflects green light [2].

2.1.2. Chemical energy

Chemical energy is stored in the chemical bonds within atoms, between atoms, and in the interaction forces between molecules. In the human body, a large amount of chemical energy is stored for a long time in glycogen and some of it is stored temporarily in ATP molecules. When energy is needed for human life activities, ATP is hydrolyzed, its high-energy bonds are broken and chemical energy which is stored in high-energy phosphate bonds is released.

2.1.3. Electric energy and Electric signal

Electric energy is caused by the movement of charges. In the human body, nerve cells are filled with charged ions, and nerve cells consume chemical energy to transport charged ions in order to create a potential difference between the inside and outside of cell membrane. When a nerve cell is stimulated, the flow of charged ions changes, the potential difference and the electrical energy change, which in turn generates an electrical signal.

2.1.4. Mechanical energy

Mechanical energy is the sum of kinetic energy and potential energy. It can describe the state of motion and height of an object, while the kinetic and potential energy of an object can be transformed between them. In the human body, when a muscle contracts, it also means that kinetic and potential energy are changed and energy is output as mechanical energy.

2.2. Photosynthesis — The conversion between solar energy and chemical energy

Photosynthesis is a process that occurs in chloroplasts of green plants that converts solar energy into chemical energy for storage in organic matter.

In the light reaction, chlorophyll absorb sun light and water molecules in chloroplasts to gain the energy of photons and undergo photolysis. The light energy carried by protons is transferred to electrons, which are then converted into unstable chemical energy. At the same time, the H+ generated by the photolysis of water leads to a difference in H+ concentration inside and outside the thylakoid membrane, allowing the potential energy of H+ to be used to drive ATP synthase, which is converted into chemical energy stored in ATP. Thus, in the light reaction, the conversion of light energy to chemical energy and potential energy to chemical energy occurs [3].

In the dark reaction, the chemical energy in ATP and NADPH is transferred to organic matter represented by glucose for storage.

2.3. Cellular respiration — Release of chemical energy

Although humans cannot directly convert and store solar energy through photosynthesis like producers such as plants, they can obtain and store energy by ingesting food. When needed for life activities, chemical energy stored in organic matter such as glucose is released by respiration and transferred to ATP, which can be further rapidly hydrolyzed, releasing large amounts of chemical energy instantaneously.

2.4. Resting potentials and nerve impulses — Conversion of chemical and electrical energy

In resting neurons, ATP is hydrolyzed to provide energy to the sodium-potassium protein pump, pumping K^+ into the cell and Na^+ out of the cell, which in turn generates the flow of charged ions that give the neuron electrical energy and resting potential. In fact, the chemical energy released by ATP is not directly converted into electrical energy, but is used to produce electrical energy indirectly after being used [4].

In the nerve impulse, when the resting potential neuron is stimulated, a large amount of Na^+ enters the cell from outside the neuron, and the high concentration of Na^+ diffuses along the neural axis on both sides, generating a local current, and when the local current reaches the threshold that can open the surrounding Na^+ channel, the neuron is further activated and the nerve impulse is generated. The neuron has electrical energy. In the process of local current generation, no direct conversion of chemical and electrical energy occurs.

When the nerve impulse reaches the synapse, the high concentration of Na^+ triggers Ca^{2+} flow inward, resulting in the release of neurotransmitters from the synaptic front into the synaptic gap, which eventually binds to the receptor cell membrane, and the electrical energy is converted back into a chemical signal.

2.5. Muscle contraction – Conversion of chemical and mechanical energy

Muscle cells are composed of myofibrils which are composed of myosin and actin. Muscle contraction requires contraction commands and energy support. Chemical signals are transmitted from motor neurons to muscle cells to form muscle contraction instructions, and the completion of the instructions requires the release of chemical energy from ATP hydrolysis and the conversion of chemical energy to mechanical energy to provide energy support.

In terms of the process of muscle contraction, when motor neuron synapses in the neuromuscular junction release acetylcholine to the muscle cell, large amounts of calcium ions are released from the sarcoplasmic reticulum to bind to troponin at the top of actin in muscle cells, changing the actin conformation, exposing the binding site on actin to myosin [5]. In turn, energy from ATP can start the cross-bridge movement between actin and myosin, leading to the sliding of myofilaments towards the Z-line and the overall presentation as muscle contraction.

From the energy point of view, the conversion of chemical energy to mechanical energy is reflected in three main stages.

1) The binding of ATP to the head of myosin allows the hydrolysis of ATP to produce DP and Pi and release chemical energy to change from a low-potential conformation to a high-potential conformation. At the same time, the process of ATP hydrolysis allows the molecular structure of myosin to change, and the distance between myosin and actin is thus shortened, making it possible for the two to bind and form a cross-bridge [5].
2) Cross-bridges are formed between actin and myosin when actin receives instructions to expose the binding site. And the chemical energy released by ATP is converted into mechanical energy to change the angle of the cross-bridge, followed by myosin pulling the actin toward the M-line, shortening the sarcomere length. When myosin length is shorted simultaneously in many muscle cells, the whole muscle contracts.
3) During muscle contraction, ADP and Pi are released, myosin and actin remain connected until new ATP binds to myosin before they are disconnected, myosin and actin return to their initial positions, ATP is hydrolyzed, myosin returns to a low potential conformation, and the muscle relaxes.

3. Conclusion

Life activities require energy support, which is reflected in the transfer and conversion of energy. In this paper, we take muscle contraction as an example and explain that energy originates from the sun, is fixed by producers, and is transferred to top consumers through food chains and food webs via trophic levels. After acquiring food, chemical energy is released through respiration and achieves support for muscle contraction by the conversion of chemical, electrical, and mechanical energy. This paper explains the energy transfer and transformation during muscle contraction from an interdisciplinary microscopic perspective, which provides a reference for understanding the relationship between energy and life activities.

Conflict of interest: The authors declare no conflict of interest.

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