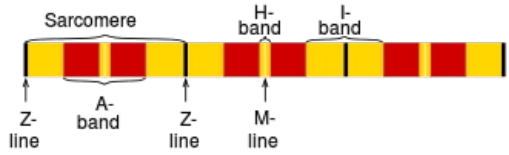
Biomechanics of muscle contraction

Introduction

A muscle is a motor organ of animals, which has the task of changing the chemical energy of bonds into kinetic energy with the help of the work done by its contraction - contraction. Muscle differs from other biological viscoelastic substances in its capacity for active contraction and a relatively high degree of elasticity. A non-contracted muscle resists deformation when lengthened beyond the so-called resting length. When the deforming force ceases to act, the muscle returns to its resting length. When the applied force increases beyond the limit of strength, the muscle tears. This limit varies in the range of 0.4–1.2 MPa for individual muscles.

Muscle - structure

The basic building block of skeletal muscle is the muscle fiber – a long multinucleated cell with a diameter of about 50 μm and a length of several cm. This multinucleate formation was created during differentiation by the fusion of several uninucleate embryonic cells - myoblasts.



At the subcellular level, the muscle fiber consists of many thinner filaments - myofibrils with a diameter of 0.5-1 μm. Each myofibril is divided lengthwise into identical repeating sections called sarcomeres. On longitudinal sections of myofibrils, 2 bands can be distinguished: A – anisotropic, I – isotropic. Their regular alternation is the cause of the transverse striation of skeletal muscles, which can be observed with a polarizing microscope . The isotropic band is divided in the middle by a narrow dark band (Z-disk).

Myofibrils are further formed by two types of longitudinally formed fibers - filaments: stronger with a diameter of 10-15 nm, symmetrically surrounded by six weaker ones with a diameter of 5-6 nm. Only thin fibers are found in band I, both types of fibers at the edge of band A, only thicker fibers in the middle of band A. These filaments are made up of two structural proteins: actin and myosin . Myosin is contained in stronger fibers, actin in weaker fibers. Another structural protein in muscles is titin , whose function is to bind the myosin filaments to the Z-disc.

Muscle - function

According to Huxley and Hansen's theory (AF Huxley - 1917, British neurophysiologist, Nobel prize for medicine in 1963), the essence of muscle contraction lies in the insertion of weaker actin fibers between stronger myosin fibers. Self-contraction occurs due to the formation of temporary cross-bridges between myosin molecules in thick filaments and actin molecules in thin filaments.

The necessary energy for this process is obtained by the hydrolysis of ATP , catalyzed by actin-activated ATP-ase, contained in myosin macromolecules. Calcium cations play an important role in the regulation of muscle contraction .

The stimulus for muscle contraction is supplied by a nerve fiber in the form of an action potential. The place where the nerve enters the muscle is referred to as the neuromuscular plate and represents a type of chemical synapse where the mediator of impulse transmission is acetylcholine . It is released by depolarization caused by an action potential from the terminal part of the nerve fiber. The plasma membrane of the muscle fiber (sarcolemma) contains a large number of acetylcholine receptors, which are essentially ligand-gated sodium channels. Acetylcholine opens these channels and enables the flow of sodium ions into the muscle cell, the transfer of irritation to this cell and thus the creation of a muscle contraction.

Contraction

There are two forms of muscle contraction: Isotonic (at constant load) and isometric (at constant length). During contraction, heat is released and mechanical work is done . When calculating muscle work, however, we encounter the fact that the calculation of physical work is equal to the product of the magnitude of the force and the path along which it acts. Only an isotonic contraction in which the length of shortening can be measured fits this definition.

In isometric contraction, the length of the muscle is constant, the path according to the physical definition is equal to zero, so the amount of work cannot be calculated in this way. However, the muscle still does the work. For its calculation, it is necessary to use indirect calorimetry methods. A measure of this work is oxygen consumption during contraction.

Both forms of muscular work release heat. In an isotonic contraction, this heat has 2 components:

Activation heat - it is a manifestation of chemical changes that bring the muscle from a state of rest to a state of movement.

Contractile heat – this is released during muscle shortening and is given by the product of the constant (3.5.10 -4 Jm -3) and muscle shortening.

The total energy released during the work phase of isotonic contraction is given by the relation:

$$\mathbf{E= Q_a + Q_z + W}$$

Q a is the heat of activation,

Q z is the shortening heat,

W is the mechanical work equal to the working stroke, i.e. the product of the load P and the shortening x.

A time recording of the contraction of an isolated muscle is called a **myogram** . The shortening does not occur immediately after irritation, but only after a short latency period, which is the time required to activate the contraction mechanisms.

Links

related articles

- Muscle
- Muscle spindle
- Contraction of heart muscle
- Connection of excitation and contraction

Literature

- HRAZDIRA, Ivo – MORNSTEIN, Vojtěch. *Lékařská biofyzika a přístrojová technika.* 1. edition. Brno : Neptun, 2001. 381 pp. ISBN 80-902896-1-4.