EDUCATIONAL AND METHODICAL COMPLEX OF DISCIPLINE
OMiF1214 Morphology and physiology of human body
Course – 1 Semester – 2
Number of credits – 8
Almaty 2021

Lecture №4
The muscular system 3
Muscle Metabolism

Outcomes:

1. explain how skeletal muscle meets its energy demands during rest and exercise;
2. explain the basis of muscle fatigue and soreness;
3. discuss why extra oxygen is needed even after an exercise has ended;
4. distinguish between two physiological types of muscle fibers, and explain their functional roles;
5. discuss the factors that affect muscular strength; and
6. discuss the effects of resistance and endurance exercises on muscles.

Muscle contractions are fueled by adenosine triphosphate (ATP), an energy-storing molecule. Four potential sources of ATP power muscle contractions.

Free ATP
Low levels of ATP exist within the muscle fibers and can immediately provide energy for contraction. However, the pool is very small and after a few muscle twitches will be exhausted.

Phosphocreatine
Phosphocreatine, also known as creatine phosphate, can rapidly donate a phosphate group to ADP to form ATP and creatine under anaerobic conditions. Enough phosphocreatine is present in the muscle to provide ATP for up to 15 seconds of contraction.
The reaction of phosphocreatine + ADP to ATP + creatine is reversible. During periods of rest, the store of phosphocreatine is regenerated from ATP.

Glycolysis
Glycolysis is the metabolic reaction which produces two molecules of ATP through the conversion of glucose into pyruvate, water, and NADH in the absence of oxygen. The glucose for glycolysis can be provided by the blood supply, but is more often converted from glycogen in the muscle fibers. If glycogen stores in the muscle fibers are expended, glucose can be created from fats and proteins. However, this conversion is not as efficient. Pyruvate is continually processed into lactic acid. With pyruvate accumulation, the amount of lactic acid produced is also increased. This lactic acid accumulation in the muscle tissue reduces the pH, making it more acidic and producing the stinging feeling in muscles when exercising. This inhibits further anaerobic respiration, inducing fatigue.
Glycolysis alone can provide energy to the muscle for approximately 30 seconds, although this interval can be increased with muscle conditioning.

Cellular Respiration
While the pyruvate generated through glycolysis can accumulate to form lactic acid, it can also be used to generate further molecules of ATP. Mitochondria in the muscle fibers can convert pyruvate into ATP in the presence of oxygen via the Krebs Cycle, generating an additional 30 molecules of ATP.
Cellular respiration is not as rapid as the above mechanisms; however, it is required for exercise periods longer than 30 seconds. Cellular respiration is limited by oxygen availability, so lactic acid can still build up if pyruvate in the Krebs Cycle is insufficient.
Cellular respiration plays a key role in returning the muscles to normal after exercise, converting the excess pyruvate into ATP and regenerating the stores of ATP, phosphocreatine, and glycogen

in the muscle that are required for more rapid contractions.

Muscle Fatigue

Muscle fatigue occurs following a period of sustained activity.

Lactic Acid Accumulation

Long-term muscle use requires the delivery of oxygen and glucose to the muscle fiber to allow aerobic respiration to occur, producing the ATP required for muscle contraction. If the respiratory or circulatory system cannot keep up with demand, then energy will be generated by the much less efficient anaerobic respiration.

In aerobic respiration, pyruvate produced by glycolysis is converted into additional ATP molecules in the mitochondria via the Krebs Cycle. With insufficient oxygen, pyruvate cannot enter the Krebs cycle and instead accumulates in the muscle fiber. Pyruvate is continually processed into lactic acid. With pyruvate accumulation, lactic acid production is also increased. This lactic acid accumulation in the muscle tissue reduces the pH, making it more acidic and producing the stinging feeling in muscles when exercising. This further inhibits anaerobic respiration, inducing fatigue.

Lactic acid can be converted back to pyruvate in well-oxygenated muscle cells; however, during exercise the focus in on maintaining muscle activity. Lactic acid is transported to the liver where it can be stored prior to conversion to glucose in the presence of oxygen via the Cori Cycle. The amount of oxygen required to restore the lactic acid balance is often referred to as the oxygen debt.

Ion Imbalance

Contraction of a muscle requires Ca^{+}ions to interact with troponin, exposing the actin binding site to the myosin head. With extensive exercise, the osmotically active molecules outside of the muscle are lost through sweating. This loss changes the osmotic gradient, making it more difficult for the required Ca^{+}ions to be delivered to the muscle fiber. In extreme cases, this can lead to painful, extended maintenance of muscle contraction or cramp.

Nervous Fatigue and Loss of Desire

Nerves are responsible for controlling the contraction of muscles, determining the number, sequence, and force of muscular contractions. Most movements require a force far below what a muscle could potentially generate, and barring disease nervous fatigue is seldom an issue. However, loss of desire to exercise in the face of increasing muscle soreness, respiration, and heart rate can have a powerful negative impact on muscle activity.

Metabolic Fatigue

Depletion of required substrates such as ATP or glycogen within a muscle result in fatigue as the muscle is not able to generate energy to power contractions. Accumulation of metabolites from these reactions other than lactic acid, such as Mg^{2+} ions or reactive oxygen species, can also induce fatigue by interfering with the release of Ca^{+}ions from the sarcoplasmic reticulum or through reduction in the sensitivity of troponin to Ca^{+}.

Exercise and Aging

With sufficient training, the metabolic capacity of a muscle can change, delaying the onset of muscle fatigue. Muscle specified for high-intensity anaerobic exercise will synthesise more glycolytic enzymes, whereas muscle for long endurance aerobic exercise will develop more capillaries and mitochondria. Additionally, with exercise, improvements to the circulatory and respiratory systems can facilitate better delivery of oxygen and glucose to the muscle.

With aging, levels of ATP, CTP, and myoglobin begin to decline, reducing the muscle's ability to function. Muscle fibers shrink or are lost and surrounding connective tissue hardens, making muscle contraction slower and more difficult. Exercise throughout life can help reduce the impact of aging by maintaining a healthy oxygen supply to the muscle.

Questions for control

1. From which two molecules can ADP borrow a phosphate group to become ATP? What is the enzyme that catalyzes each transfer?
2. In a long period of intense exercise, why does muscle generate ATP anaerobically at first and then switch to aerobic respiration?

3. List four causes of muscle fatigue.
4. List three causes of excess postexercise oxygen consumption.
5. What properties of fast glycolytic and slow oxidative fibers adapt them for different physiological purposes?

Basic literature:

1. Saladin, Kenneth S: Anatomy & Physiology. The Unity of Form and Function (2016, McGraw-Hill Education) на англ. яз.
2. Costanzo, Linda S.: BRS Physiology. Board Review Series.7 edition. -Wolters Kluwer Health, 2018.- 307p. - ISBN 1496367693, 9781496367693
3. Leslie P. Gartner: Color Atlas and Text of Histology. - 7th Edition. - Wolters Kluwer, 2017. ISBN 1496346734, 9781496346735
4. Russell K. Hobbie, Bradley J. Roth: Intermediate Physics for Medicine and Biology. - Springer, 2015. - ISBN 3319126822, 9783319126821
5. Andersson D, Medical Terminology: The Best and Most Effective Way to Memorize, Pronounce and Understand Medical Terms: Second Edition, ISBN-13 : 978-1519066626, 2016