Force generation in skeletal-muscle system

Assoc. Prof. H. Burak KANDİLCİ

- In order to understand how muscle generates force and how is modulated by length of it , we must understand the behaviour of the muscle fiber during the isometric contraction

- Force is needed to strecth the muscle to different muscle lengths. This force is called resting tension.

- When we strecth muscle passively to different lengths we see that resting tension is increasing. This is passive resting lenth tension. When the muscle is stimulated as there is a fixed muscle length a second force is generated. This is active tension. The total tension is the sum up of two tensions

- The active tension amount is dependent on the passive resting muscle length. Active tension is greatest at a resting muscle length, lets say at a value of Lmax. Active tension is smaller at before and after Lmax values. So Lmax is the optimal length for contraction. This mechanism is the bases for Frank Starling mechanism for the heart striated muscle.

- The amount of active tension developed by a muscle fiber during contraction can be altered by changing the initial resting length of the fiber. This is also valid for the skeletal muscle

- Actually when we focus to the sarcomeres during this process. Sarcomeres produce maximal tension when thick and thin filaments overlap between about 80 percent to 120 percent, approximately 1.6 to 2.6 micrometers.

- Muscles exist in this state to optimize the force produced during contraction, which is modulated by the interlaced myofilaments of the sarcomere. When a sarcomere contracts, myosin heads attach to actin to form cross-bridges. Then, the thin filaments slide over the thick filaments as the heads pull the actin.

- This results in sarcomere shortening, creating the tension of the muscle contraction. If a sarcomere is stretched too far, there will be insufficient overlap of the myofilaments and the less force will be produced. If the muscle is over-contracted, the potential for further contraction is reduced, which in turn reduces the amount of force produced.

- Simply put, the tension generated in skeletal muscle is a function of the magnitude of overlap between actin and myosin myofilaments. In mammals, there is a strong overlap between the optimum and actual resting length of sarcomeres.

- That means, unlike in cardiac muscle, skeletal muscle fibres are maintained near their optimal length in their working range; therefore, the Frank-Starling length–tension relationship is not a major factor in skeletal muscle physiology.

- Consequently, the force generated by a single skeletal muscle fibre will be a function of both the cross-sectional area and the length of the fibre.

- The same relationship applies to the muscle as a whole. Of course, it would not be very useful if each muscle could contract only at its maximum force.

- Graded muscular contraction is achieved through two main mechanisms: summation and recruitment.

- The increase in muscle tension from successive action potentials occurring during the phase of mechanical activity is known as summation

- Summation was releated with stimulus frequency. Increasing stimulus rate increases contractile force until the tetanic contraction was achieved.

- Single motor neurons innervate multiple muscle fibres. A motor neuron and the muscle fibres it innervates are collectively called a motor unit. The number of muscle fibres within a motor unit varies within and between muscles.

- When a muscle is required to produce a progressive increase in tension, initially, when the load applied to the muscle is small, the smallest motor units within the muscle are used.

- As the load increases larger and larger motor units are recruited, so that when the load is the maximum attainable by that muscle, all its motor units will be operating.

- The process of increasing the number of motor units that are active in a muscle at any given time is called recruitment. It is achieved by activating excitatory synaptic inputs to more motor neurons. The greater the number of active motor neurons, the more motor units recruited, and the greater the muscle tension.

- Motor neuron size plays an important role in the recruitment of motor units. The size of a motor neuron refers to the diameter of the nerve cell body, which is usually correlated with the diameter of its axon.

- Given the same number of sodium ions entering a cell at a single excitatory synapse in a large and in a small motor neuron, the small neuron will undergo a greater depolarization because these ions will be distributed over a smaller membrane surface area.

- Accordingly, given the same level of synaptic input, the smallest neurons will be recruited first—that is, will begin to generate action potentials first.

- The larger neurons will be recruited only as the level of synaptic input increases. Since the smallest motor neurons innervate the slow-oxidative motor units, these motor units are recruited first, followed by fast-oxidative motor units, and finally, during very strong contractions, by fast-glycolytic motor units

As we know from the perivious the biophysical events in contraction relaxation of the muscle lecture that;

The mechanical response of a single muscle fiber to a single action potential is known as a twitch. There are two types of twitch. Isometric and isotonic. When a muscle develops tension but does not shorten (or lengthen), the contraction is said to be isometric (so the length is constant).

- A contraction in which the muscle shortens, while the load on the muscle remains constant, is said to be isotonic (so there is constant tension). In the figure you see an isotonic twitch

- Comparing isotonic and isometric twitches in the same muscle fiber, one can see from right trace that the latent period in an isotonic twitch is longer than that in an isometric contraction, while the duration of the mechanical event—shortening—is briefer in an isotonic twitch than the duration of force generation in an isometric twitch.

- Moreover, the characteristics of an isotonic twitch depend upon the magnitude of the load being lifted: At heavier loads: (1) the latent period is longer, (2) the velocity of shortening (distance shortened per unit of time) is slower, (3) the duration of the twitch is shorter, and (4) the distance shortened is less.

- A closer look at the sequence of events in an isometric twitch explains this load-dependent behavior. Following excitation, the cross-bridges begin to develop force, but shortening does not begin until the muscle tension just exceeds the load on the fiber.

- Thus, before shortening, there is a period of isometric contraction during which the tension increases. The heavier the load, the longer it takes for the tension to increase to the value of the load, when shortening will begin. If the load on a fiber is increased, eventually a load is reached that the muscle is unable to lift, the velocity and distance of shortening will be zero, and the contraction will become completely isometric.

- So Load also affects Velocity of contraction; It is a common experience that light objects can be moved faster than heavy objects. That is, the velocity at which a muscle fiber shortens decreases with increasing loads. The shortening velocity is maximal when there is no load and is zero when the load is equal to the maximal isometric tension.

- At loads greater than the maximal isometric tension, the fiber will lengthen at a velocity that increases with load. The shortening velocity is determined by the rate at which individual cross-bridges undergo their cyclical activity. Because one ATP is split during each crossbridge cycle, the rate of ATP splitting determines the shortening velocity. Increasing the load on a crossbridge slows its forward movement during the power stroke. This reduces the overall rate of ATP hydrolysis, and thus the velocity of shortening.