Contraction of a Skeletal Muscle as a Whole

Graded Responses

In skeletal muscles, the "all-or-none" law of muscle physiology applies to the *muscle cell*, not to the whole muscle. It states that a muscle cell will contract to its fullest extent when it is stimulated adequately; it never partially contracts. However, skeletal muscles are organs that consist of thousands of muscle cells, and they react to stimuli with **graded responses,** or different degrees of shortening. In general, graded muscle contractions can be produced two ways: (1) by changing the *frequency* of muscle stimulation, and (2) by changing the *number* of muscle cells being stimulated.

A whole muscle's response to different rates of stimulation (fig.3):

(a) ***twitch contraction***, a single stimulus is delivered, and the muscle contracts and relaxes. This is not the normal way of muscles operation. It is a result of certain nervous system problem.

(b) ***Summing of contraction,*** stimuli are delivered more frequently, so the muscle does not have time to completely relax; contraction force increases because the effects of the individual twitches are summed. This is the most type muscles activity.

(c) ***Unfused tetanus***, more complete fusion of the twitches occurs as stimuli are delivered at a still faster rate.

(d) ***Fused tetanus***, a smooth continuous contraction without any evidence of relaxation, results from a very rapid rate of stimulation.

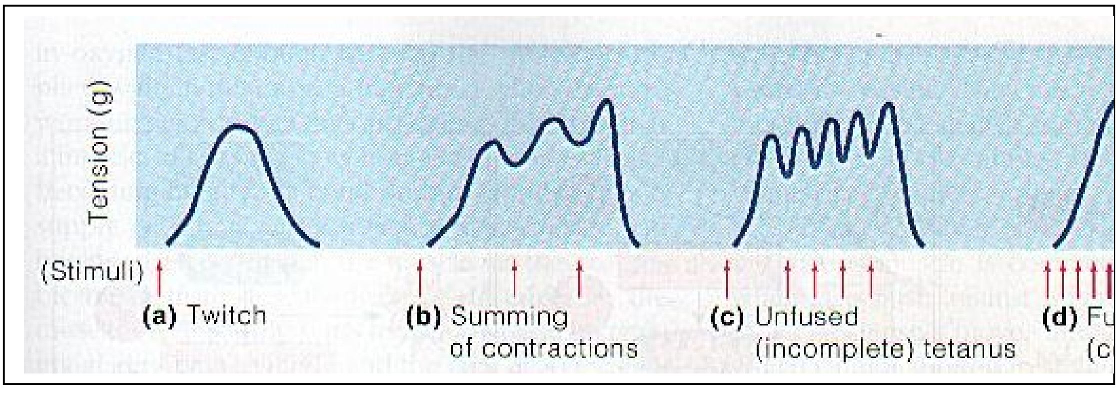

Fig. (3):A whole muscle's response to different rates of stimulation

Providing Energy for Muscle Contraction

Since ATP is the *only* energy source that can be used directly to power muscle activity, ATP must be regenerated continuously if contraction is to continue.

Essentially, working muscles use three pathways for ATP regeneration:

1. **Direct phosphorylation of ADP by creatine phosphate.** The unique high-energy molecule **creatine phosphate (CP)** is found in muscle fibers but not other cell types. As ATP is being depleted, interactions between CP and ADP result in transfers of a high-energy phosphate group from CP to ADP, thus regenerating more ATP in a fraction of a second.

2. **Aerobic respiration**. At rest and during light to moderate exercise, some 95 percent of the ATP used for muscle activity comes from aerobic respiration. Aerobic respiration occurs in the mitochondria and involves a series of metabolic pathways that use oxygen. These pathways are collectively referred to as *oxidativephosphorylation.* During aerobic respiration, glucose is broken down completely to carbon dioxide and water, and some of the energy released as the bonds are broken is captured in the bonds of ATP molecules. Al-though aerobic respiration provides a rich ATP harvest (36 ATP per 1 glucose), it is fairly slow and requires continuous delivery of oxygen and nutrient fuels to the muscle to keep it going.

3. **Anaerobic glycolysis and lactic acid formation**. The initial steps of glucose breakdown occur via a pathway called *glycolysis*, which does not use oxygen and hence is an *anaerobic* part of the metabolic pathway. During glycolysis, which occurs in the cytosol, glucose is broken down to pyruvic acid, and small amounts of energy are captured in ATP bonds (2 ATP per 1 glucose molecule). Anaerobic glycolysis produces only about 5 percent as much ATP

from each glucose molecule as aerobic respiration. However, it is some 2 1/2 times faster, and it can provide most of the ATP needed for 30 to 60 seconds of strenuous muscle activity.

Muscle Fatigue and Oxygen Debt

If exercise muscles strenuously for a long time, **muscle fatigue** occurs. A muscle is fatigued when it is unable to contract even though it is still being stimulated. Without rest, an active or working muscle begins to tire and contracts more weakly until it finally ceases reacting and stops contracting. Muscle fatigue is believed to result from the **oxygen debt** that occurs during prolonged muscle activity. When muscles lack oxygen, lactic acid begins to accumulate in the muscle via the anaerobic mechanism. In addition, the muscle's ATP supply starts to run low. The increasing acidity in the muscle and the lack of ATP cause the muscle to contract less and less effectively and finally to stop contracting altogether.

True muscle fatigue, in which the muscle quits entirely, rarely occurs in most of us because we feel fatigued long before it happens and we simply slow down or stop our activity.

Types of Muscle Contractions

The event that is common to all muscle contractions is that *tension* develops in the muscle as the actin and myosin myofilaments interact and the myosin cross bridges attempt to slide the actin-containing filaments past them within the muscle fibers.

Isotonic contractions are more familiar to most of us. In iso-tonic contractions, the myofilaments are successful in their sliding movements, the muscle shortens, and movement occurs. Bending the knee, rotating the arms, and smiling are all examples of isotonic contractions.

Contractions in which the muscles do not shorten are called **isometric contractions**. In isometric contractions, the myosin myofilaments are "skidding their wheels," and the tension in the muscle keeps increasing. They are trying to slide, but the muscle is pitted against some more or less immovable object. For example, muscles are contracting isometrically when you try to lift a 400-pound dresser alone. But when you push against a wall with bent elbows, the wall doesn't move, and the triceps muscles, which cannot shorten to straighten the elbows, are contracting isometrically.

Muscle Tone

Even when a muscle is voluntarily relaxed, some of its fibers are contracting— first one group and then another. Their contraction is not visible, but, as a result of it, the muscle remains firm, healthy, and constantly ready for action. This state of continuous partial contractions is called **muscle tone.** Muscle tone is the result of different motor units, which are scattered through the muscle, being stimulated by the nervous system in a systematic way.