Theory of electromyography

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Electromyography is a discipline that deals with the detection, analysis and use of electrical signal that emanates from skeletal muscles. The electromyography is studied for various reasons in the medical field. Even a superficial acquaintance with scientific literature will uncover various current applications in fields such as neuro physiology, kinesiology, motor control, psychology, rehabilitation, medicine and biomedical engineering.

The EMG signal is the electrical manifestation of the neuromuscular activation associated with the contracting muscles. The signal represents the current generated by the ionic flow across the membrane of the muscle fibers which propagates through the intervening tissues to reach the detection surface of the electrode located in the environment.

It is an exceedingly complicated signal which is affected by anatomical and physiological properties of muscles and the control scheme of the nervous system, as well as characteristics of the instrumentation used to detect and observe it.

Most of the relationships between the EMG signal and the properties of contracting muscles that are currently in use have evolved serendipitously. The lack of proper description of the EMG signal is probably the greatest single factor that has hampered the development of electromyography in to a precise discipline.

APPLICATIONS:

- To test the nerve and muscle activity

- To determine nerve conduction velocity to test nerve damage/compression
- To obtain firing characteristics of nerves.
- Analysis of motor unit action potentials
- To analyze the extent of nerve damage, muscular damage
- It is useful for gym trainees and sport persons to evaluate growth and development of specific muscles.
- It is useful for energy/fatigue analysis of industrial workers for time-motion-rest cycle evaluation for an efficient working environment.
- Usually passenger pilots are checked for their EMG levels before they take up a flight in order to ensure fatigue level of the pilot is at safe level.

MUSCLES:

About 40% of the human body is skeletal muscles and another 10% is smooth muscles of internal organs and cardiac muscles from the heart. Here we are interested in characterizing the function of skeletal muscles. The primary function of skeletal muscles is to generate force. Because of this, they are excitable. Thus skeletal muscles have 2 fundamental properties. They are excitable(able to respond to stimulus) and contractible(able to produce tension). A skeletal muscle consists of numerous fibers with diameters ranging from 10 to 80 µm. Each muscle fiber contains hundreds to thousands of myofibrils . Each myofibril has about 1500 myosin filaments and 3000 actins filaments lying side by side.

Cell Potential:

The nervous system is comprised of neuron cells. Neurons are the conducting elements of the nervous system and are responsible for transferring information across the body. Only these and muscle cells are able to generate potentials and therefore are called excitable cells. Neurons contain special ion channels that allow the cell to change its membrane potential in response to the stimuli the cell receives.

Receiving Potential:

All cells in the body have a cell membrane surrounding them. Across this membrane there is an electric charge referred to as the resting potential. This electric impulse is generated by differential ion permeability of the membrane. In the cells, potassium (k+) channels allow diffusion of k+ ions out of the cell while Sodium(Na+) ions diffuse in to the cell. This Na+-K+ pump, which requires ATP to operate, pumps two K+ ions in to the interior of the cell for every 3 Na+ ions pumped out. K+ and Na+ ions are continuously diffusing across the membrane from where they were just pumped, but at a slower rate. Since there are more K+ ions inside the cell than outside, a potential exists.

Action Potential:

Some cells, such as skin cells are not excitable. Other cells such as nerve and muscle cells are excitable. When a simulating electric field acts on an excitable cell, the Na+ permeability increases, Na+ enters the cell interior and the entering positive charge depolarizes(reduces to approximately zero), the transmembrane potential. Later the K+ permeability increases and K+ ions flow out to counter this effect. The Na+ gates close followed by the K+

gates. Finally, the resting potential is regenerated. The action potential lasts about 1ms in nerves and about 100 ms in cardiac muscle. It propagates in nerves at about 60 m/s and carries sensations from the periphery toward the brain via sensory nerves. Through motor nerves, the brain commands muscles to contract. We can calculate the action potential propagation velocity v= d/t where

Figure shown here represents the role of voltage-gated ion channels in the action potential. The circled numbers on the action potential correspond to the 4 diagrams of voltage-gated sodium and potassium channels in a neuron's plasma membrane.

Motor Unit:

The most fundamental unit of a muscle is called the Motor Unit. It consists of an alpha-motoneuron and all the muscle fibers that are enervated by the motoneuron's branches. The electrical signal that emanates from the activation of muscle fibers of a motor unit that are in the detectable vicinity of an electrode is called MOTOR UNIT ACTION POTENTIAL (MUAP). This constitutes the fundamental unit of the EMG signal.

A Schematic representation of the genesis of a MUAP is presented above. There are many factors that influence the shape of MUAP. Some of these are

The relative geometrical relationship of the detection surface of the electrode and the muscle fiber of the motor unit in its vicinity. The relative position of the detection surfaces to the innervated zone, which is the region where the nerve branches contact the muscle fibers. The size of muscle fibers, because amplitude of individual action potential is proportional to the diameter of the fiber, andThe number of muscle fibers of an individual motor unit in the detectable vicinity of the electrode.

The last two factors have particular importance in clinical applications. Considerable work has been performed to identify morphological modifications in the MUAP shape resulting from modifications in the morphology of the muscle fibers or the motor unit such as regeneration of motoneurons. Although usage of MUAP shape analysis is common practice among neurologists, interpretation of the result is not always straight forward and relies heavily on the experience and disposition of the observer.

To sustain muscle contraction, the motor unit must be activated repeatedly. The resulting sequence of MUAP's is called Motor Unit Action Potential Train(MUAPT). So, EMG signal can be synthesized by linearly summing the MUAPT's as they exist when they are detected by the electrode where mathematically generated MUAPT's are added to yield the signal at the bottom.

MUSCLE CONTRACTION:

As an action potential travels along a motor nerve to muscle fibers, it initiates an action potential along the muscle fiber membrane, which depolarizes the muscle fiber membrane and travels with in the muscle fiber. The Subsequent electro-chemical reaction with in the muscle fiber then initiates attractive forces between the actin and myosin filaments and causes them to slide together. This mechanism produces muscle contraction.

Tension is developed in the muscle as it contracts. There are 3 types of contraction

- Isometric
- Concentric
- Eccentric

Isometric or Static Contraction means a muscle contracts without change in its length. Concentric Contraction occurs when a load is less than the isometric force produced by the muscle and the load shortens the muscle. Eccentric Contraction occurs when the load is greater than the isometric force and elongates the contracting muscle.