Spinal Control of Movement

Introduction

The motor system consists of the muscles of the body and all the neurons that control them. Behavior requires the coordinated action of various combinations of almost 700 muscles in a changing and often unpredictable environment.

- The spinal cord contains certain *motor programs* for the generation of coordinated movement.
- These spinal motor programs are accessed, executed, and modified by descending commands from the brain.

This chapter focuses on the peripheral somatic motor system:

- The joints
- Skeletal muscle
- Spinal motor neurons

Somatic Motor System

The somatic motor system controls skeletal muscle.

- Contraction and relaxation of skeletal muscle:
    - Moves bones and causes movement of most of our body.
    - Moves the eyes and parts of our face.
    - Causes breathing.
    - Produces speech.

General Muscle Organization

- Skeletal muscles are enclosed in fibrous connective tissues that extend from each end of the muscle to form tendons.
- Each skeletal muscle contains hundreds of skeletal muscle cells, each innervated by a single axon branch.

Movements and Related Terminology

- Flexor – Muscle that move bones of a joint closer together when the muscle contracts.
- Extensor – Muscle that move bones of a joint further apart when the muscle contracts.
- Agonists (Synergists) – Muscles that move a bone in one direction.
- Antagonists – Muscles that move a bone in an opposite direction.
- Axial muscles – Muscles that move the trunk.
- Proximal muscles – Muscles that move the shoulder, elbow, hip, or knee.
- Distal muscles – Muscles that move the wrists, hands, ankles, feet, or digits.

The Lower Motor Neuron

Lower motor neurons are motor neurons in the spinal cord.

- The cell bodies of the somatic neurons are located in the ventral (anterior) horn of the spinal cord.
- These somatic motor neurons receives inputs from neurons in the brain (upper motor neurons), from other neurons in the spinal cord, and from sensory neurons.

The Segmental Organization of Lower Motor Neurons

- Axons from the somatic motor neurons leave the spinal cord through the ventral (anterior) roots.
- The ventral roots join with the dorsal roots to form 30 pairs of spinal nerves. (refer back to the somatosensory chapter)
- In general, the greater the number of muscles the greater the number of somatic motor neurons.
    - Cervical enlargement of the spinal cord is enlarged because of the large number of muscles in the arms and hands.
    - The lumbar enlargement of the spinal cord is enlarged because of the large number of muscles in the thighs, legs and feet.

Alpha Motor Neurons

Somatic motor neurons are often called Alpha motor neurons.

- Alpha motor neurons directly control the force of skeletal muscle contraction.
- Motor Units consist of an Alpha motor neuron and all the muscle <u>cells</u> it innervates.

Graded Control of Muscle Contraction by Alpha Motor Neurons

- The force of contraction of a single muscle <u>cell</u> is determined by the firing rate of a motor neuron.
    - One presynaptic action potential in a motor neuron causes an EPSP in the muscle cell large enough to trigger one postsynaptic action potential in the muscle cell, and thus a single muscle contraction (twitch).
- The force of contraction of an <u>entire</u> muscle is determined, in addition, by the number of muscle cells stimulated.
    - Stimulation of additional synergistic motor neurons (recruitment) will of course stimulate additional muscle cells.

Inputs to Alpha Motor Neurons

- From neurons in the brain (upper motor neurons).
- From other neurons (interneurons) in the spinal cord.
- From sensory neurons.

Types of Muscle an dMotor Units

- Red Muscle is slowly fatiguing and uses oxidative energy metabolism (highly oxygen dependent).
- White Muscle is rapidly fatiguing and uses anaerobic metabolism (much less oxygen dependent).

Neuromuscular Matchmaking

- Action potential firing pattern affects muscle phenotype
    - Slow, steady firing neurons cause the development of Red muscle and slow motor units.
    - Fast, burst firing neurons cause the development of White muscle and fast motor units.

Excitation-Contraction Coupling

The contraction of a skeletal muscle cell is controlled by a motor neurons by the secretion of a neurotransmitter at a synapse with the muscle cell. This arrangement is the same as the synapse between one neuron and another neuron.

Muscle Fiber (Cell) Structure

- Skeletal muscle cells are much like most other cells in the body with three major exceptions.
    - Skeletal muscle cells and long and cylindrical, much like spaghetti, and have multiple nuclei.
    - Skeletal muscle cells contract a tremendous quantity of contractile proteins.
    - Skeletal muscle cells are excitable like neurons
- Skeletal muscle cells exhibit:
    - Myofibrils which are the bundles of contractile proteins.
    - A sarcoplasmic reticulum that wraps around the myofibrils and stores calcium.
    - Transverse tubules which connect between the plasma membrane and the sarcoplasmic reticulum.
    - A motor endplate (a postsynaptic portion of the plasma membrane)

The Molecular Basis of Muscle Contraction

The process of neuromuscular excitation-contraction coupling can be summarized as follows:

Excitation

1. An action potential occurs in the axon of an alpha motor neuron.
2. Acetylcholine (Ach) is secreted by the axon terminal (synapse) of the alpha motor neuron at the motor endplate.
3. Nicotinic-m receptor sodium channels in the motor endplate open and the postsynaptic membrane depolarizes.

4. Voltage gated sodium channels open, an action potential is generated which is then conducted along the plasma membrane in into the transverse tubules.
5. Depolarization of the transverse tubules cause Ca^{2+} release from the sarcoplasmic reticulum.

Contraction

1. Ca^{2+} binds to troponin and moves tropomyosin.
2. Myosin binding sites on actin are exposed.
3. Myosin heads (crossbridges) bind to actin.
4. The myosin heads (crossbridges) bend and pull the actin toward the center of the sarcomere.
5. Myosin heads disengage in the presence of ATP.
6. The ATP reenergizes (elongates the crossbridges).
7. The cycle repeats as long as Ca^{2+} and ATP are present.

Relaxation

1. As EPSPs end the plasma membrane and the transverse tubules return to their resting potentials
2. Ca^{2+} is pumped back into the sarcoplasmic reticulum.
3. Myosin binding sites on actin are covered again by tropomyosin.

Spinal Control of Motor Units

Proprioception from Muscle Spindles

The Myotatic (Stretch) Reflex

Gamma Motor Neurons

Proprioception from Golgi Tendon Organs

Proprioception from the Joints

Spinal Interneurons

Inhibitory Input

Excitatory Input

The Generation of Spinal Motor Programs for Walking