Lecture 16: Somatic Motor System:

I. Muscles are divided into categories:

a. Non-striated: **smooth**, secretory, in charge of material movement through intestines, and the control of blood pressure and its flow.

b. Striated:

- **Skeletal**: bones around joints. Each skeletal muscle is enclosed in a connective tissue sheath that 100s of muscle fibers (cell of SM). A single axon branch from the CNS innervates each muscle fiber.
- **Cardiac**: heart muscle, involuntary movement.

- Somatic motor system consists of motor neurons and innervating skeletal muscles.

II. Lower Motor Neuron:

- Only motor neurons directly command muscle contraction.

a. Ventral horn

Dorsal root receives sensory input.

Where can you find the cell body of a sensory neuron? Ganglia.

Ventral horn: body of motor neurons.

b. Segmental organization:

- Lower motor neurons bundle together from the ventral roots: each joins a dorsal root from the spinal cord to form a spinal nerve that exits the cord through notches between vertebrae.
- Motor neurons that innervate distal and proximal musculature are found mainly in the cervical, and lumbar-sacral segment, whereas those innervating axial are found at medial level.
- The cells innervating the axial muscle are medial to those innervating the distal muscles, and the innervating flexors are dorsal to those innervating extensors.
- Cell bodies are located in the left ventral horn showing the dark grey color.
- Presynaptic cell innervates the neuron. Post-synaptic cell innervates the muscle fiber.
- Each group in the spinal cord has 30 dermatomes.
- Muscles are divided into: axial (trunk); distal (hands, feet); and proximal (shoulder, elbow).

c. Alpha motor neurons:

- For every muscle's axons, there are different motor neuron pools.
- **Size principle:** muscles fibers get excited from small to large; depends on excitation and path. Small alpha neurons are recruited first larger alpha neurons.
- Directly trigger the generation of force by muscles.
- **Motor unit:** one alpha neuron and all the muscles fibers that innervates.
- **Motor neuron pool**: collection of alpha motor neurons that innervate ONE single muscle.
- **Inputs to alpha motor neurons**: lower motor neurons are controlled by synaptic inputs in the **ventral horn.**

3 major sources of input:

i. Dorsal root ganglion in charge of muscle length (sensory)
ii. Upper motor neuron in the motor cortex and brain stem, in charge of voluntary movement.
iii. Interneurons in the spinal cord, in charge of excitatory or inhibitory, motor programs in the spinal cord.

- Types of motor neurons:

a. **Fast**: rapidly fatiguing white fibers, have large diameter, and fast conducting axon. (Type II)
b. **Slow**: slower fatiguing red/white fiber, small diameter, and slower conducting axons. (Type I)

- Three input sources to alpha motor neurons:

1. Sensory input synapses to alpha motor neurons
2. SI synapses on interneuron
3. Upper motor neurons→ M1 is in the control from the brain.

- Examples:
- Long distance runner→ slow muscle fiber
- Body builder → fast muscle fiber

III. Excitation-contraction coupling:

- Overview: muscle contraction is initiated by the release of Ach from the axon terminals. Ach produces a large ESP in the postsynaptic membrane due to the muscle cell activation of **nicotinic** Ach Receptors. Muscle cells contain **voltage-gated sodium channels**, this ESPS is sufficient to evoke and action potential in the muscle fiber, which triggers the release of **Ca2+,** which leads to contraction of the fiber. Relaxation occurs when the Ca2+ levels are lowered by **reuptake** into the organelles.

a. Muscle fibers structure:

- **Myofibrils**: cylindrical structures, contract in response to an action potential sweeping down the sarcolemma. These make up the muscle fibers and contract in response to action potential.
- **T- tubules**: inside-out axons; networks tunnels. It is linked to a calcium release channel in the SR; the arrival of an action potential causes a conformational change in the voltage-sensitive tetrad of channel, leading Ca2+ flow through. (Contraction of myofibril) Connects the sarcoplasmic reticulum to the sarcolemma.
- **Sarcoplasmic reticulum**: extensive intracellular sac that stores Ca2+
- **Sarcolemma**: cell membrane that encloses muscle fibers.

o When the muscle is at rest, myosin cannot interact with actin because the myosin attachment sites on the actin molecule are covered by the protein "**troponin.**"- Binding to it will expose the site where myosin binds to actin.

b. *Excitation:*

1. Action potential occurs in the alpha neuron axon
2. Ach is released at the neuromuscular junction.
3. Nicotinic receptor channels open, and the sarcolemma depolarizes (ESPS)
4. Voltage-gated Na+ channels open, and an action potential is generated in the muscle fiber.
5. Ca2+ release from the sarcoplasmic reticulum causes a depolarization on the T tubules.

c. *Contraction:*

1. Ca2+ binds to troponin.
2. Myosin binding sites on the actin are exposed.
3. The cycle continues as long as Ca2+ and ATP are present.

d. *Relaxation:*

1. The sarcolemma and T tubules return to their resting potentials.
2. Ca2+ is sequestered by the sarcoplasmic reticulum by an ATP drive-pump.
3. Myosin binding sites on actin are covered by troponin.
   - Myofibrils are divided into disks (Z lines)
   - Muscle contraction occurs when thin and thick filaments slide along each other.
   - H band- thick
   - I band- thin (excitation occurs)
   - A band- overlapping between H and I bands.

IV. Spinal Control of motor units:

i. Myotatic Reflex: function of the muscle spindle; stretch receptor and detector.

- Overview: when a muscle is pulled on, it tends to pull back (contract). In addition, the MR involves sensory feedback from the muscle; motor neurons must receive a continual synaptic input from the muscles. The discharge of Ia sensory axons is closely related to the length of the muscle. The stretching of the equatorial region of the spindle leads to depolarization of the Ia axon endings due to the opening of mechanosensitive ion channels. The resulting increased action potential discharge of the Ia axons synaptically depolarizes the alpha motor neuron, which respond by increasing their action potential frequency.

1. **Muscle spindle:** are specialized structures located deep within most skeletal muscle. The spindles are associated Ia axons, specialized for the detection of changes in muscle length (stretch), are examples of "propioceptors." Ia axons enter the spinal cord via dorsal roots, branch repeatedly, and form excitatory synapses upon both interneurons and alpha motor neurons of the ventral horns.

2. **Knee-jerk reflex:** when your doctor ta the tendon beneath your kneecap, it stretches the quadriceps muscles, which then reflexively contracts and causes your leg to extend. (mono-synaptic reflex→ one synapse separates sensory input from motor neuron).
3. Types of muscle fibers:
   i. **Intrafusal fiber:** muscle fibers that are located within its fibrous capsule. Receive motor innervation by *gamma motor neuron*
   ii. **Extrafusal fiber:** lie outside the spindle and form the bulk of the muscles. Innervated by the alpha motor neuron.

Review: Weight on muscle→ muscle lengthens→ spindles are stretched→ depolarization of an alpha motor neuron→ muscle contracts.

iii. Gamma Motor Neuron: regulates muscle spindle responses.

1. Functions of gamma MN:
   i. Activation of alpha motor neurons causes the Extrafusal muscle fiber to shorten.
   ii. If the muscle spindle becomes slack, it goes "off the air" and no longer reports the length of muscle.
   iii. Activation of gamma MN causes the poles of the spindle to contract, keeping it "on the air"
2. **Gamma loop**: alpha activation alone decreases Ia activity, while gamma activation alone increases Ia activity. *Feedback loop*
   - Gamma MN-> intrafusal muscle fiber-> Ia Afferent axon-> alpha motor neuron-> Extrafusal muscle fiber.
   - Gamma MN controls the Myotatic reflex loop, sets desired muscle length, and it is compensated by alpha MN.
   - Reverse Myotatic reflex: fine motor. Polysynaptic reflex.

- Golgi tendon organ: source of propio receptive inputs from muscle and muscle force of contraction. PRESSURE RECEPTOR. They are located at the junction of the muscle and the tendon, are innervated by a group of Ib sensory axons, which are smaller that Ia axons. Ib activity from the Golgi tendon organs encodes *muscle tension* information. Ia activity from the spindles encodes *muscle length*.
- Reverse Myotatic reflex protects the muscle from being overload. Its normal function is to regulate muscle tension within an optimal rate.
  a. Decreased alpha motor neurons is increased muscle contraction.
- Tension receptor: causes relaxation and reverse myotactic reflex.
  - Reciprocal inhibition: the contraction of one set of muscles accompanied by the relaxation if the antagonist muscle.

Spinal interneurons: polysynaptic- all mediated by innervating spinal interneurons; spinal interneurons receive synaptic input from primary sensory axons, descending axon from the brain, and collaterals of lower motor neuron axons.

i. Crossed-extensor reflex:
- Activation of the extensor muscles and the inhibition of the flexors of the opposite side.
- Reciprocal inhibition, but in this case, activation of the flexors on one side of the spinal cord is accompanied by the inhibition of the flexors on the opposite side.

ii. Locomotion:
- Central pattern generators: circuits that give rise to rhythmic motor activity.
- Electrical stimulation of the stumps of axons descending from the brain can generate alternating rhythmic activity in the spinal cord, mimicking that which occurs during swimming. Activation of the NMDA receptors on spinal interneurons was sufficient to generate locomotor activity.

iii. Circuit for rhythmic Alternating activity:

1. The membrane depolarizes
2. Na2+ and Ca2+ flow into the cell through the NMDA receptors
3. Ca2+ activates potassium channels
4. K+ flows out of the cell
5. The membrane hyperpolarizes.
6. CA2+ stops flowing into the cell.
7. K+ channels close.
8. Membrane depolarizes, and cycle repeats.