MOTOR UNITS
Sequence of electrical and chemical events leads to muscle contraction

**Electrical events**
- \(\alpha MN\) action potential
- Action potential in muscle fiber
- End plate potential
- Contraction of muscle fiber

**Neuromuscular junction**
- Presynaptic site (\(\alpha MN\) axon)
- Postsynaptic site (muscle fiber)

**Course of afferent fibers**
- In
- Dorsal root ganglion
- Dorsal root
- Dorsal horn
- Ventral horn
- Dorsolateral cell group
- Ventromedial cell group
- Motor nucleus (to axial muscle)
- Motor nucleus (to limb muscle)

**Location of motor nuclei**
- Dorsal
- Intermediate zone
- Ventral
- In
- Dorsal root ganglion
- Dorsal root
- Dorsolateral cell group
- Ventromedial cell group
- Motor nucleus (to axial muscle)
- Motor nucleus (to limb muscle)

**Alpha motor neurons**
Muscles contract slowly and the force generated by a train of impulses summates

Active tension varies with the rate of stimulation

A

Muscle tension

5 Hz twitch

Motor neuron activity

B

20 Hz

C

80 Hz

D

100 Hz

Active tension depends upon the pattern of stimulation

A

Extra impulse

B

C

Missing impulses

1 sec

Sharp rise in tension evoked by extra spike correlates with sudden increase in Ca²⁺ concentration in the muscle fiber

[Ca²⁺]

Muscle tension
Three basic types of mammalian skeletal muscle fibers

**Type 1**, or red, fibers are specialized for slow, sustained, aerobic exercise.

**Type 2**, or white, fibers are specialized for rapid contractions.

- **Type 2a** capable of rapid contractions that can be sustained for a relatively long time without fatigue.
- **Type 2b** capable of rapid contractions, duration of which is limited by fatigue.
A single motor neuron and the muscle fibers it innervates constitute a motor unit

Type 2B

The location of individual muscle fibers making up the motor unit in soleus muscle
Three types of motor units

Type 1 (slow)

Type 2A (fast fatigue-resistant)

Type 2b (fast fatigable)
A muscle is innervated by a pool of motor neurons

Organization of *m. gastrocnemius* and *m. soleus* motor neuron pools
The motor nuclei of the spinal cord are grouped functionally in distinct medial and lateral positions.
Size principle

Motor units are recruited in fixed order
The nervous system grades the force of muscle contraction by increasing of firing rate of motor units and by recruitment of new motor units.

Activity of motor units during voluntary contractions of a fingers extensor muscle:

- **A** (low force)
- **B** (greater force)
- **C** (greatest force)

Motor units are recruited in a fixed order from weakest to strongest.

Increases in firing rate of motor units produce increasing force output.
Skeletal muscles are low-pass filters of neural input

The oscillation in the muscle tension lags behind the changes in stimulus frequency

Changes in frequency of the sinusoidal stimulation cause changes in the frequency and amplitude of muscle tension

Rapid voluntary limb movements are associated with a triphasic pattern of muscle contraction.
Conclusions

1. Muscle contraction is produced by an orderly sequence of electrical and chemical events, beginning with an action potential originating at the neuromuscular junction. Skeletal muscle fibers translate the electrical signal into a mechanical movement as a result of the spatial organization of intramuscular contractile proteins and excitable membrane channels both on the plasma membrane and on the sarcoplasmic reticulum.

2. Individual muscle fibers are classified into three types (1, 2a and 2b) according to their contractile and metabolic properties. The properties of a whole muscle depend on the proportion of muscle fiber types it contains and on the architectural arrangement of muscles fascicles with respect to connective tissues, bones and joints.

3. The motor unit is defined as a single motor neuron and the group of muscle fibers it innervates. All muscle fibers in a single motor unit consist of the same muscle fiber type. The amount of the force produced by the muscle fibers of a motor unit is governed by the pattern and frequency of action potentials produced by the motor neuron. Three types of motor units – slow, fast fatigue-resistant, and fast fatigable – can be categorized on the basis of their twitch speed and fatigability.

4. Each muscle is innervated by a pool of motor neurons, which typically contains a mixture of motor unit types, although in different proportions depending on the typical use of that muscle. An orderly sequence of motor neuron activation within a pool leads to activation of units producing the smallest amount of force before those producing larger amounts of force. This sequence, known as a size principle, results from passive electrical properties of motor neurons and their synaptic inputs. Alternative recruitment sequences can occur when synaptic inputs have a specialized distribution among motor neurons that overrides the contribution of the passive electrical properties of motor neurons.

5. Precision in the control of movement is complicated by their slow response to neural activation. Because the mechanical response of muscles to neural activity is slow, changes in muscle tension do not represent a simple one-to-one correspondence to the firing patterns of motor neurons. Rather, the temporal pattern of the incoming train of action potentials is modified by the muscles themselves. Because of this filtering action, muscles faithfully reproduce only those signals that vary slowly. To produce rapid changes in tension, the motor systems must alternate contraction in opposing muscles.