I. Resting membrane potential

A. Definition – Potential electrical difference across living cells
B. Usually cell is negative inside relative to outside

II. Generation of the resting membrane potential

A. Resting state (steady state)
   1. Equimolarity
   2. Electrical neutrality
   3. Zero electrochemical gradient

B. Basis for the resting membrane potential
   1. Ions responsible are primarily Na\(^+\) and K\(^+\).
   2. Factors influencing magnitude of the action potential are primarily the concentrations of Na\(^+\) and K\(^+\).

C. Calculation of the resting membrane potential
   1. Nernst equation:  
      \[ E = \frac{-RT}{zF} \ln \left( \frac{K_i}{K_o} \right) \]
      Where E = potential difference across the membrane (usually in mV)
      R = gas constant
      T = absolute temperature
      F = Faraday's constant (# charges per mole ion)
      z = valence of ion

   2. Modified Nernst equation
      \[ R \text{ and } F = \text{ constants} \]
      \[ T (20^\circ C) = 293 \text{ absolute} \]
      \[ z \text{ for } K^+ = 1 \]
      Convert ln to log\(_{10}\), so that:  
      \[ E \text{ (in mV)} = -58 \log_{10}[K_i]/[K_o] \]
3. Goldman equation

\[
E = -58 \log_{10} \left( \frac{P_K[K_o] + P_Na[Na_i] + P_Cl[Cl_o]}{P_K[K_o] + P_Na[Na_o] + P_Cl[Cl_i]} \right)
\]

Where \( P \) = permeability coefficient

**II. Motor innervation of muscle**

A. Motor neuron

1. Branched (can innervate many myofibers) \( \rightarrow \) terminal axons.
2. Absolute terminal innervation ratio: one myofiber innervated by one terminal axon.

B. The motor unit

1. Each motor neuron innervates several muscle fibers within a muscle.
2. Size of motor unit varies with muscle and fineness of movement.
   a. There are 100 to 200 myofibers per motor neuron in larger muscles.
      -- *rat soleus*, 200 fibers/neuron; *rat gastrocnemius*, 1,000 fibers/neuron
   b. There are fewer in muscles such as ocular muscles.

C. The neuromuscular junction

1. Terminal axon
   a. Vesicles (contain acetylcholine)
   b. Presynaptic membrane
   c. Synaptic cleft

*Fig. 6.2. The fine structure of a vertebrate motor end-plate and nerve ending, seen in longitudinal section, as determined by light microscopy. *mf*, myofibril; *m.n.*, muscle nucleus; *ax*, axon; *tel*, Schwann cell (teloglia) nucleus; *sarc*, sarcoplasm; *my*, myelin sheath. (From Couteaux, 1960.)*
2. Myofiber
   a. Postsynaptic membrane – sarcolemma
   b. Synaptic clefts – increase surface area

D. Transmission of impulse across the synaptic cleft – synaptic delay of the action potential

1. Acetylcholine
   a. End-plate potentials
   b. Quantal nature of transmitter release – each vesicle contains $10^3$ to $10^4$ molecules of acetylcholine

2. Acetylcholinesterase
   a. In synaptic cleft degrades acetylcholine
   b. Stops transmission signal, contraction
III. Motor unit recruitment

A. The motor unit

1. A motor unit consists of one motor neuron and all of the muscle fibers it contracts.
2. Size of motor unit varies with muscle and fineness of movement.
3. All muscles consist of a number of motor units and the fibers belonging to a motor unit are dispersed and intermingle amongst fibers of other units.
4. The muscle fibers belonging to one motor unit can be spread throughout part, or most of the entire muscle, depending on the number of fibers and size of the muscle.
IV. Force of contraction and motor unit recruitment

A. Motor unit recruitment depends on the force/resistance of the exercise.
   1. With light intensity exercise the Type I (slow twitch) motor units are recruited.
   2. When the load is increased, the Type IIa (fast twitch) will be recruited with the help of the Type I fibers.
   3. When the load becomes even greater, the Type IIb/x will be recruited with the help of the Type IIa and Type I motor units.

B. Type I motor units are always firing no matter what the intensity.

V. Motor unit recruitment, firing frequency, and fatigue

A. The central nervous system can increase strength of muscle contraction by:
   1. Increasing the number of active motor units.

B. During muscle fatigue, new motor units are recruited.
   1. A 30% decline in maximal voluntary contractions was associated with a 23% increase in motor unit recruitment.
   2. This occurs within 25 – 35 seconds.

C. When nearly all motor units are recruited, increase in firing frequency becomes the primary me
VI. Proprioceptors

A. Definition

1. Provide information about the extent of muscle stretch (muscle spindles).
2. Provide information about the extent of muscle contraction (Golgi tendon organs).

B. Components

1. Muscle spindles: small intrafusal contractile organs with afferent and efferent neurons
2. Golgi tendon organs: small stretch receptors in tendons with afferent innervation only
VII. Muscle spindles

A. Location and function

1. Muscle spindles are in parallel with myofibers (intrafusal).
2. Detect muscle stretch.

B. Structure

1. Small muscle fibers (4-7 mm long) that contain contractile proteins.
2. Have afferent and efferent fibers (fusimotor neurons).
3. Stretch of spindle signals muscle to contract (resists overstretching)
   b. Can be stimulated to contract when muscle relaxes by efferent motoneurons.
VIII. Golgi tendon organs

A. Location and function
   1. Golgi tendon organs are in series with myofibers, embedded in tendons at ends of muscles.
   2. Detect contraction (tension).

B. Structure
   1. Approximately 0.7 mm long
   2. Contain afferent fibers only
      a. Contraction of muscle signals muscle to relax — polysynaptic transmission.
      b. Inhibit skeletal muscle neuron pool in spinal cord.

Fig. 8.10. A human muscle spindle demonstrated with the adenosine triphosphatase reaction. Large fibers in the center are type I, the small round fibers associated with them are type II. The capsule surrounding the intrafusal fibers can barely be seen with this reaction.

Fig. 13–9. — Semischematic representation of a Golgi tendon organ. This receptor is innervated by branches of a thick myelinated fiber (Ib) and also by some unmyelinated fibers (C fibers) (broken lines). The role of the Ib fibers is to convey tension information to the central nervous system. That of C fibers is less well understood, but it is believed that they may convey painful stimuli to the CNS. (Adapted from Barker, D., in Barker, D. [ed.]: Muscle Receptors [Hong Kong, China: Hong Kong University Press, 1962], p. 227.)
IX. Muscle spindles vs Golgi tendon organs

A. Muscle stretch increases discharge in muscle spindles

1. Signals travel to spinal cord.
2. Muscle is stimulated to contract; discharge in muscle spindle ceases.
3. Muscle spindle contracts; discharges resume.

B. Muscle contraction increases discharge in Golgi tendon organs.

1. Signals travel to spinal cord.
2. Inhibitory neurons cause muscle to relax.