ANSC (FSTC) 607
Physiology and Biochemistry of Muscle as a Food
Motor Unit Recruitment

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

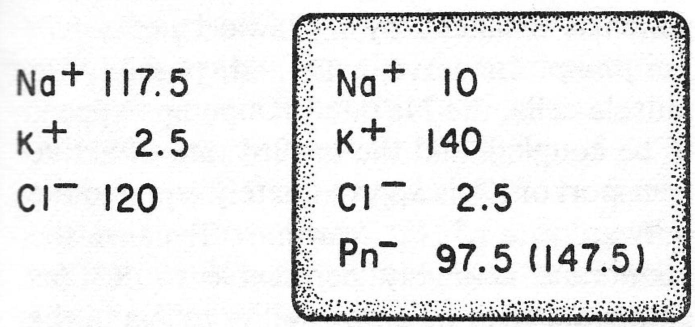
A. Resting state (steady state) requirements

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^+.

Fig. 2–3.—Schematic representation of the distribution of major ions on either side of the membrane of a frog muscle cell. The column to the right of the ions indicates the concentration of each, in millimoles per liter. Pn^- is intracellular protein; the number in parentheses is the number of millequivalents of protein; i.e., the equivalent concentration of univalent ion. Note that intracellular fluid is rich in potassium (K^+) and that the extracellular medium is high in sodium (Na^+) and chloride (Cl^-).



C. Calculation of the resting membrane potential

1. Nernst equation: $E = (-RT)/zF)ln[K_i]/K_o]$

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 and F = constants
T (20°C) = 293 absolute
z for $K^+ = 1$
Convert *ln* to $\log_{10}$, so that: E (in mV) = $-58 \log_{10}[K_i]/[K_o]$

3. Goldman equation

$$E = -58 \log_{10} \frac{P_K[K_o] + P_{Na}[Na_i] + P_{Cl}[Cl_o]}{P_K[K_o] + P_{Na}[Na_o] + P_{Cl}[Cl_1]}$$

Where P = permeability coefficient

II. Motor innervation of muscle

A. Motor neuron

1. Branched (can innervate many myofibers) → 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

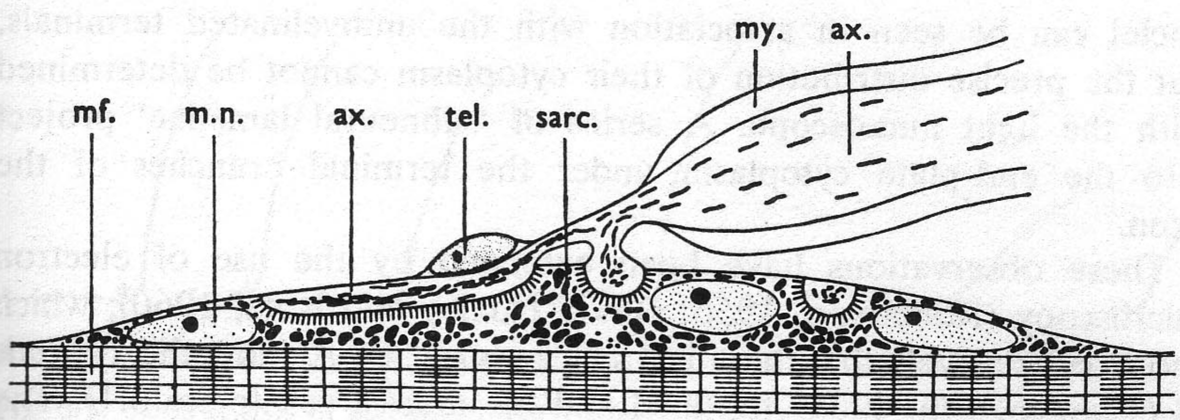
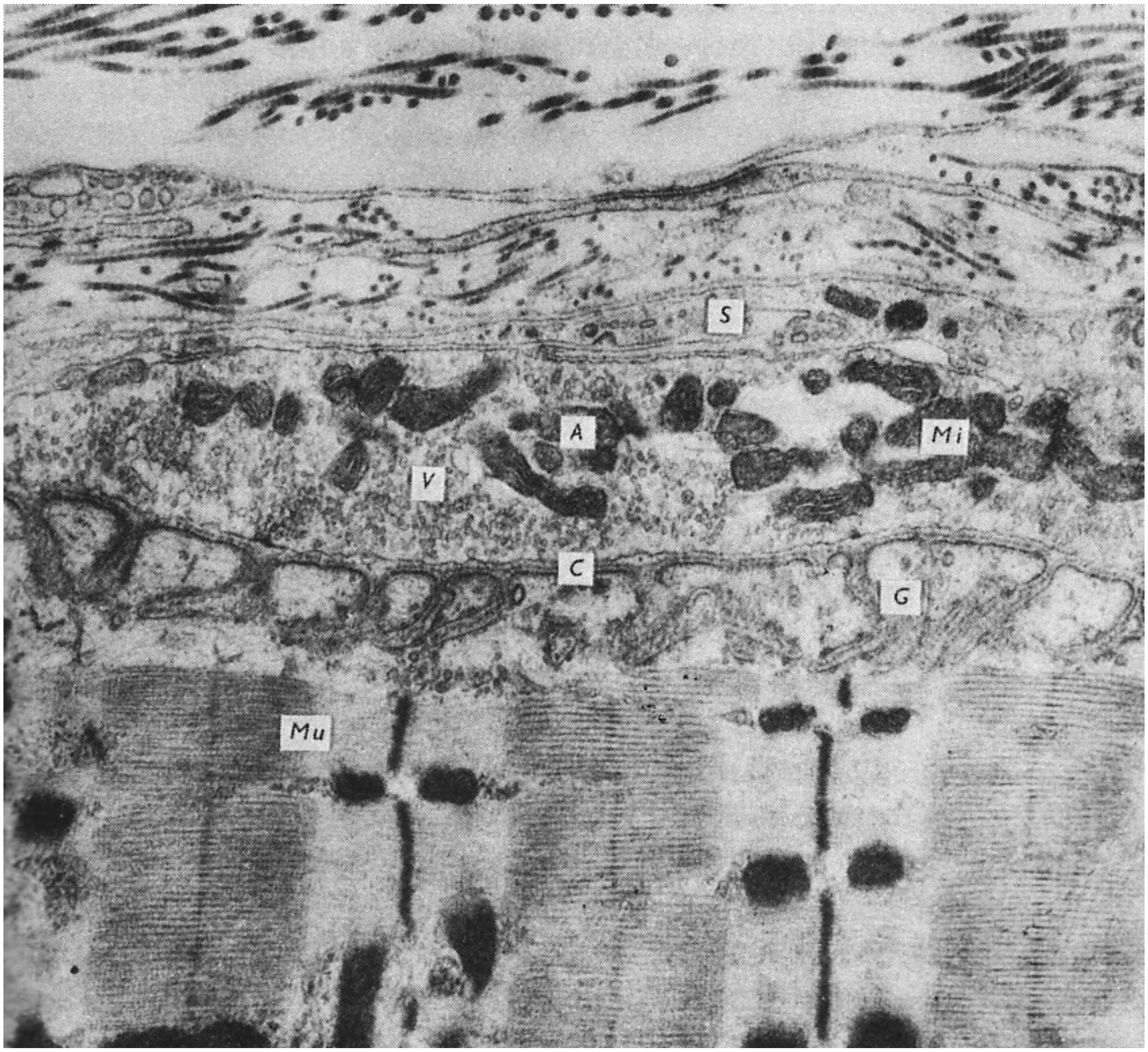


Fig. 6.2. The fine structure of a vertebrate motor end-plate and nerve ending, seen in longitudinal section, as determined by light microscopy. *mf*, myofibril; *m.n.*, muscle nucleus; *ax*, axon; *tel*, Schwann cell (teloglia) nucleus; *sarc*, sarcoplasm; *my*, myelin sheath. (From Couteaux, 1960.)

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

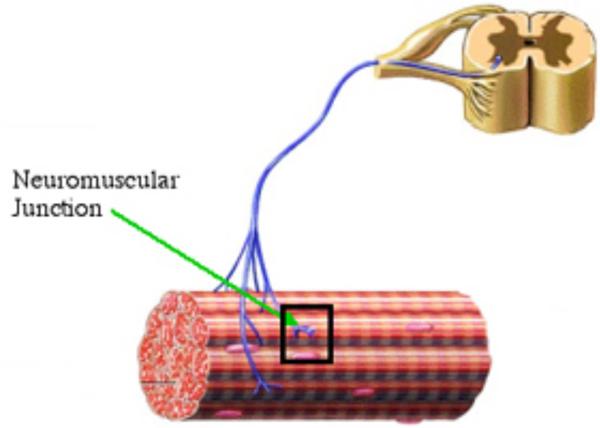
   b. Stops transmission signal, contraction

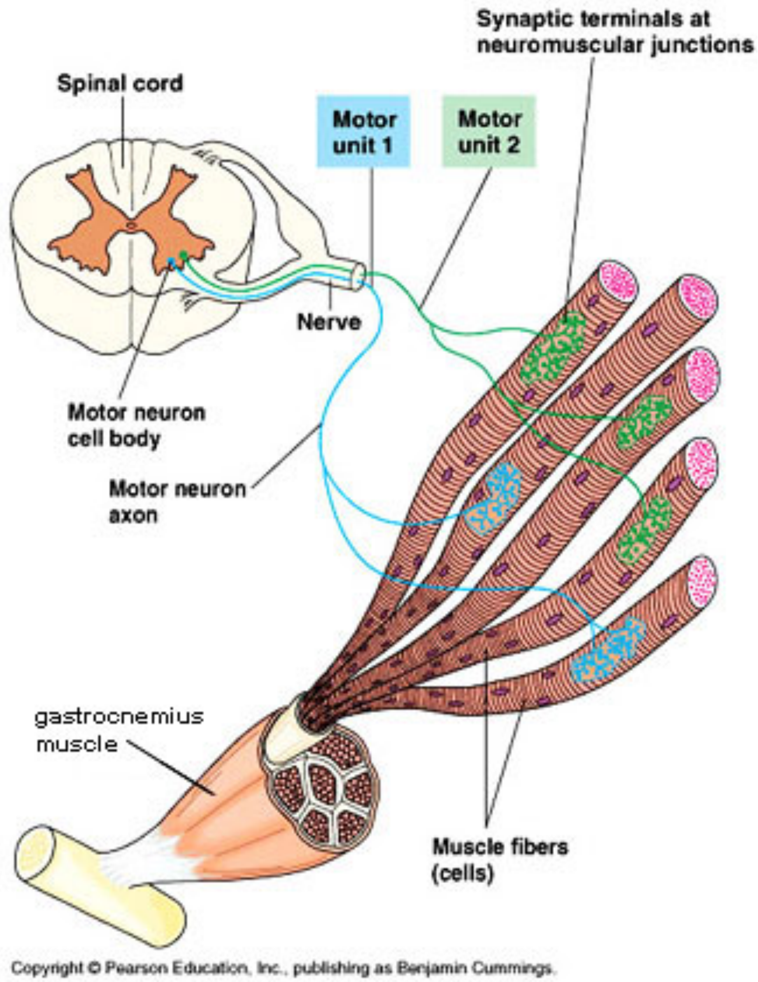
III. Motor unit recruitment

A. The motor unit

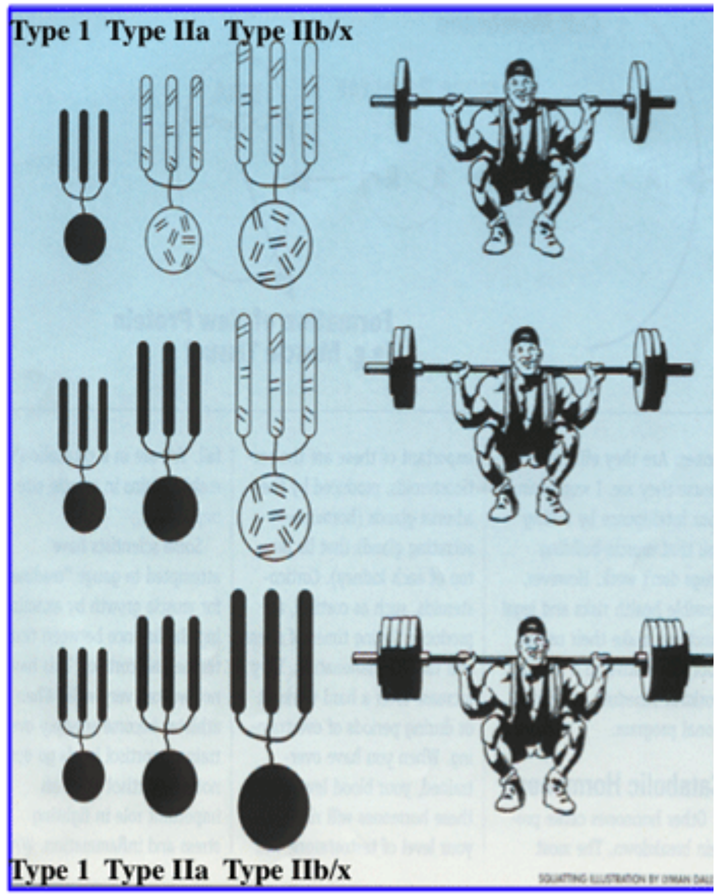
1. A motor unit consists of one motor neuron and all of the muscle fibers it contracts.
2. Size of motor unit varies with muscle and fineness of movement.
3. All muscles consist of a number of motor units and the fibers belonging to a motor unit are dispersed and intermingle amongst fibers of other units.
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

◆ One motor nerve innervates many muscle fibers





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

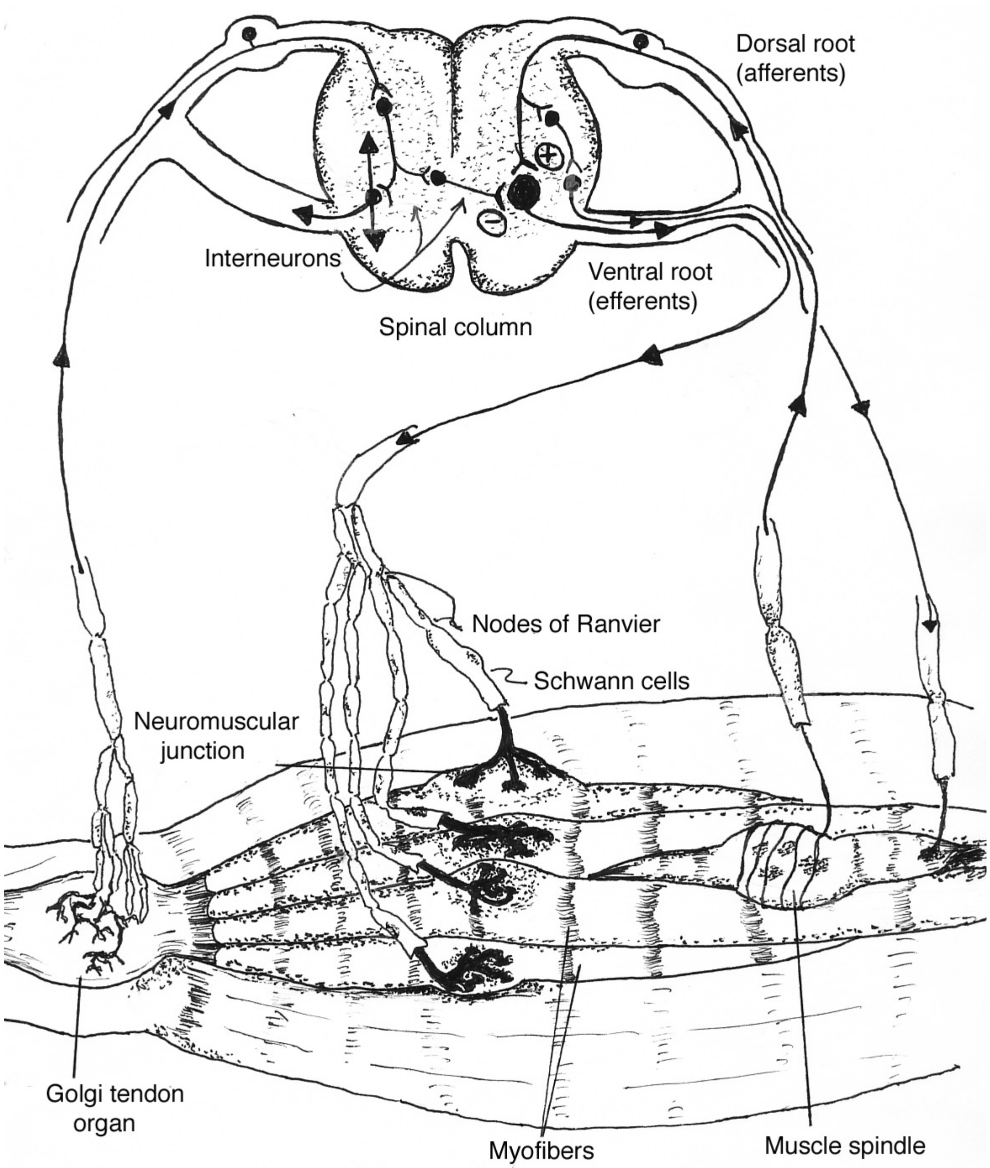
VI. Proprioceptors

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)
   a. Stimulates skeletal muscle neuron pool in spinal cord – ***monosynaptic*** transmission.
   b. Can be stimulated to contract when muscle relaxes by efferent motoneurons.

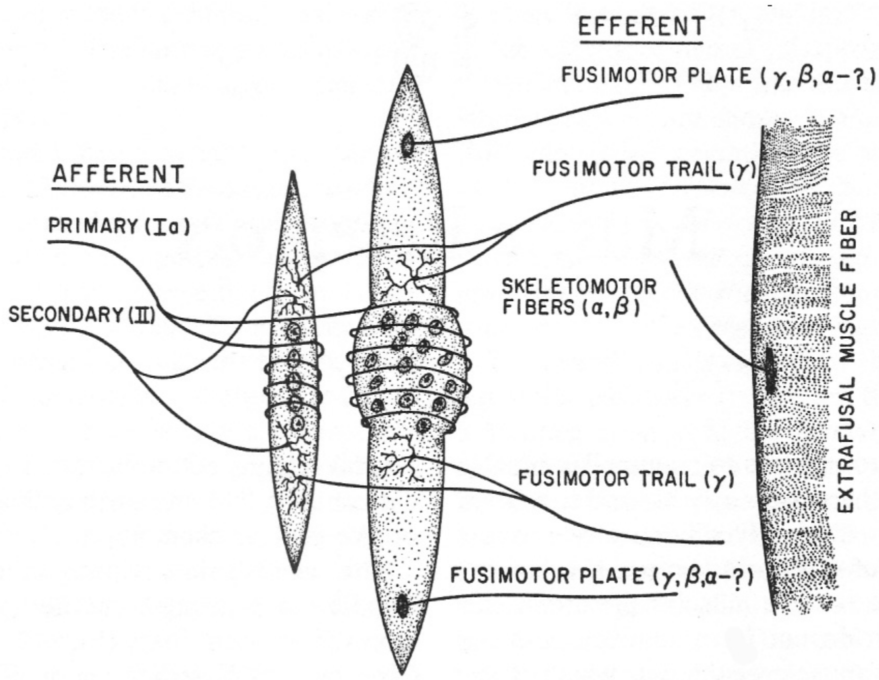


Fig. 13–1.—Diagram of the sensory and motor innervation of the muscle spindle. Note that the primary (Ia) afferent fibers innervate both the nuclear bag intrafusal fibers and the nuclear chain intrafusal fibers and that they coil around the region containing the nuclei. The secondary (II) afferents innervate *mostly* the nuclear chain fibers. In some cases they do innervate the nuclear bag fibers, but for the sake of simplicity that innervation has been omitted from the diagram. The motor innervation is provided by (1) the fusimotor plate endings, which form the terminations of γ, β and, in some cases, α fibers; and (2) the fusimotor trail endings, which are supplied by γ fibers alone. Although there is considerable overlap, plate endings are found mostly on the bag fibers, and trail endings are found mostly on the chain fibers. Again for the sake of simplicity, the plate endings (designated p_1 and p_2 in the text) are presented as one entity; however, as described in the text, their morphology is different, and they probably arise from different types of motor fibers. The skeletomotor fibers going to extrafusal muscle fibers consist of motor fibers in the α and β range.

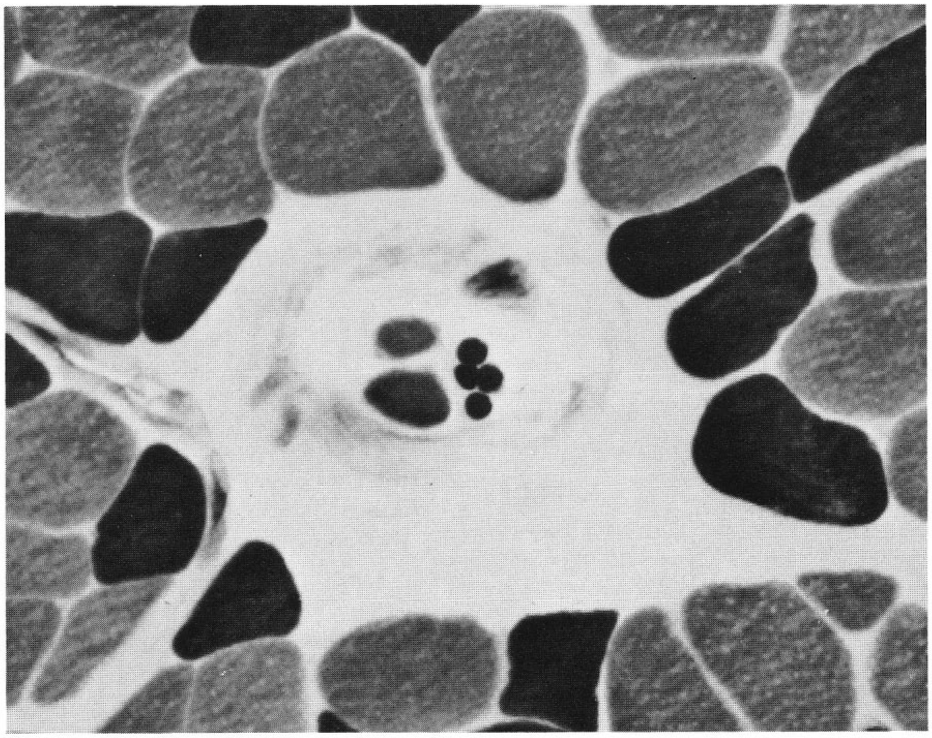


Fig. 8.10. A human muscle spindle demonstrated with the adenosine triphosphatase reaction. Large fibers in the center are type I, the small round fibers associated with them are type II. The capsule surrounding the intrafusal fibers can barely be seen with this reaction.

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.

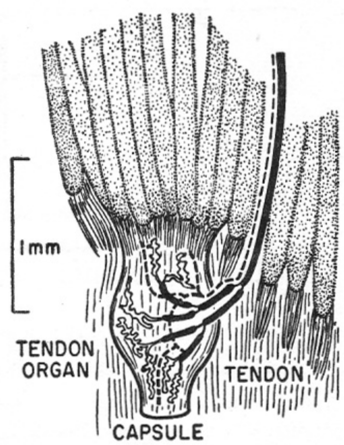


Fig. 13–9.—Semischematic representation of a Golgi tendon organ. This receptor is innervated by branches of a thick myelinated fiber (Ib) and also by some unmyelinated fibers (C fibers) *(broken lines).* The role of the Ib fibers is to convey tension information to the central nervous system. That of 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.

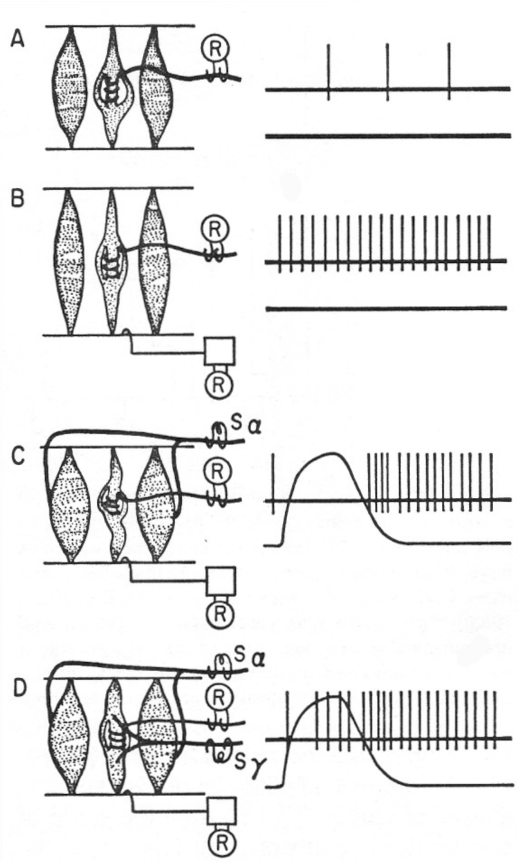


Fig. 13–3.—Diagram of the effects of stretch and muscle contraction (extrafusal and intrafusal) on spindle afferent discharges. In all records, the upper traces represent the discharge from the spindle afferent fibers recorded through the *R* electrodes, and the lower traces are recordings of muscle tension registered through a strain gauge (*R*, hooked to the muscle tendon). In **A**, the muscle is at rest length. In **B**, stretch of the muscle is increased. In **C**, a single shock applied to the skeletomotor fibers (S_α) induces muscle twitch and a pause in the spindle discharge. Shortening of the muscle relaxes the spindle because the latter is in mechanical parallel with the extrafusal muscle fibers. In **D**, both the extrafusal and the intrafusal muscle fibers have been activated simultaneously by applying electric shocks to both skeletomotor and fusimotor fibers—S_α and S_γ, respectively.

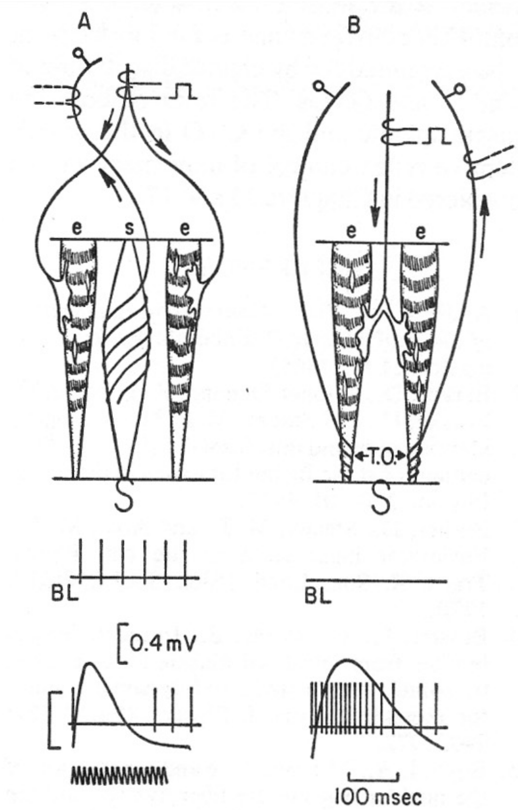


Fig. 13–10.—Mechanical model of the following anatomic arrangements: **A**, the muscle spindle *(s)* in mechanical parallel with the muscle fibers *(e)*; and **B**, the Golgi tendon organ *(T.O.)* in series with the extrafusal muscle fibers. (Modified from Fulton, J. F., and Pi-Suñer, J.: Am. J. Physiol. 83:554, 1928.) The bottom part of the illustration shows the afferent discharges and muscle tension changes during muscular contraction. In **A**, the upper record shows baseline *(BL)* discharge of a spindle afferent fiber. The lower record shows cessation of spindle discharge during a single muscle twitch. In **B**, the upper trace is a record from a single afferent fiber connected to a tendon organ of the same muscle; note that the fiber is silent. The lower record in **B** shows that the tendon organ afferent fiber discharges during contraction of the muscle. (Drawn from Hunt, C. C., and Kuffler, S. W.: J. Physiol. 113:298, 1951.)