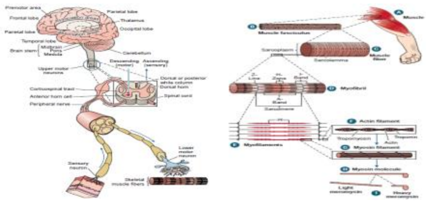
Chapter 3
Aspects of Muscle Physiology and Neurophysiology



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Learning Objectives

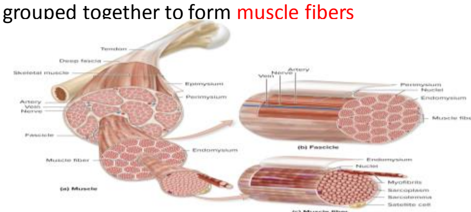
- At the end of the lecture, the students will be able to;
  - ➢ Describe the structure and types of skeletal muscle fibers and nerve fibers
  - ➢ Describe motor unit
  - ➢ Describe different types of proprioceptors

Contents

Structure of Skeletal Muscle

➢ **Organization of Muscles**

- Composed of muscle fibers that are organized into bundles (fasciculus)
- Myofilaments comprise myofibrils, which in turn are grouped together to form muscle fibers



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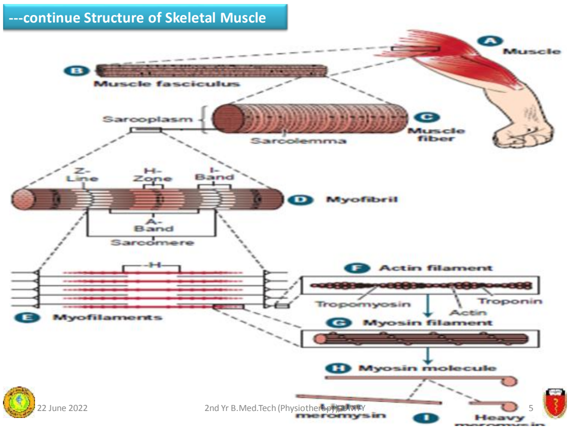

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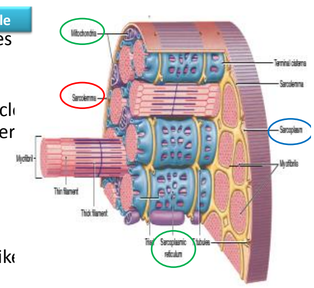
- Length of muscle fiber varies from a few mm to 60 or 70 cm
- Diameter of individual muscle fiber is 50 t0 100 micrometer (µm)
- Each fiber;
  - has covering membrane (sarcolemma)
  - Is composed of gelatin-like substance sarcoplasm
- Hundreds of contractile myofibrils and mitochondria and sarcoplasmic reticulum are imbedded in sarcoplasm



---continue Structure of Skeletal Muscle

- Mitochondria serve as "tiny factories" where metabolic processes occur
- Contractile myofibril is composed of units
- Each unit is referred to as sarcomere, portion between two Z lines
- Skeletal muscle fiber is referred to as "Striated" muscle
- Striations are alternate bands of light and dark light-reactive materials
- Each myofibril contains many myofilaments
- Myofilaments are fine threads of two protein molecules
- Actin (thin filaments) and Myosin (thick filaments)

---continue Structure of Skeletal Muscle

- Darker band in skeletal muscles, referred to as the anisotropic or A band, contains both actin and myosin filaments
- A bands have a relatively isotropic middle zone, the H zone, that contains only myosin filaments
- Lighter band in skeletal muscles, designated as the isotropic or I band
- Contains only actin filaments and is bisected transversely by a Z line
- One end of each actin myofilament within the I band is attached to the Z line.
- Muscles develop tension and shorten through electrochemical reactions between actin and myosin filaments

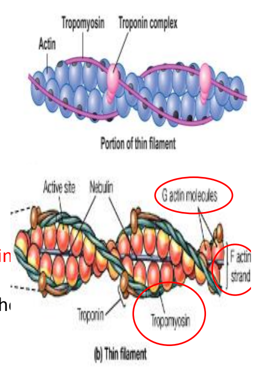
---continue Structure of Skeletal Muscle

TABLE 3-1. Defined Regions within a Sarcomere

Region	Description
A band	Dark bands caused by the presence of thick myosin myofilaments.
I bands	Light bands caused by the presence of thin actin myofilaments.
H band	Region within A band where actin and myosin do not overlap.
M line	Midregion thickening of thick myosin myofilaments in the center of H band.
Z discs	Connecting points between successive sarcomeres. Z discs help anchor the thin actin myofilaments.

---continue Structure of Skeletal Muscle

- Thin actin filaments of the I bands are comprised of *actin, tropomyosin, and troponin*
- Basic building block of actin is a globular molecule, designated as G-actin, which is about 5.5 nanometers (nm)* in diameter
- G-actin molecules are polymerized (linked together) to form a long fibrous strand, referred to as F-actin
- Two strands of F-actin are twisted about each other to form part of the actin filament
- Another filamentous protein, tropomyosin, is about 40 nm long

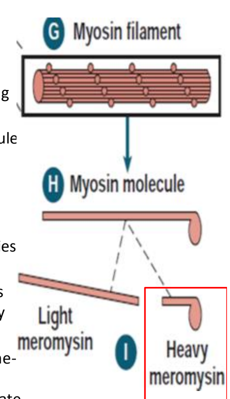


---continue Structure of Skeletal Muscle

- Two strands of tropomyosin are twisted around the double coil of F-actin in such a way as to fie in the hollows of the twisted actin
- Troponin, another globular protein, binds to a specific region of the tropomyosin filament, to give one troponin globule per 40 nm of tropomyosin filament
- An important function of troponin is *believed* to be based on its enormous avidity for calcium ions (CA^{++}), a property that is considered when discussing the activation of the contractile process
- This complex array of G-actin, F-actin, tropomyosin, and troponin comprises the actin filaments in the sarcomere.

---continue Structure of Skeletal Muscle

- Myosin filaments are thicker than actin filaments and are composed of myosin molecules that form a rod about 150 nm long and 1.5 to 2.0 nm in diameter
- Under certain conditions, the myosin molecule can be split into two fragments, one about twice the weight of the other
- The lighter weight fragment (light meromyosin) is a straight rod that is responsible for the self-aggregation properties of myosin
- The heavier fragment (heavy meromyosin) is shaped like the lower one-fourth of a hockey stick
- Heavy meromyosin fragment exhibits enzyme-like qualities capable of splitting adenosine triphosphate (ATP) into adenosine diphosphate ADP) and phosphate (PO4) plus energy



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- Within the sarcomere unit, the thick filaments *have* small projections of heavy meromyosin extending transversely from the long axis of the filament in a helical pattern.
- Transverse processes of the myosin filaments are repeated approximately *every* 43 nm and are believed to interact with specific sites on the actin filament to produce relative motion between the two types of filament.

---continue Structure of Skeletal Muscle

TABLE 3-2. **Summary of Functions of Selected Muscle Proteins**

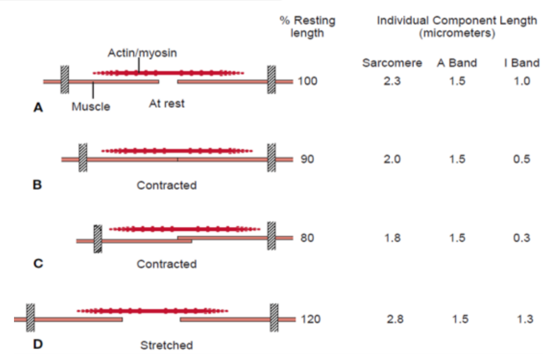
Proteins	Function
Active: Contractile	
Myosin heavy chain (several isoforms)	Molecular motor for muscle contraction–binds with actin to generate contraction force.
Actin	Binds with myosin to translate force and shorten the sarcomere
Active: Regulatory	
Tropomyosin	Regulates the interaction between actin and myosin; stabilizes actin filament
Troponin (several isoforms)	Influences the position of tropomyosin; binds with calcium ions
Myosin light chain (several isoforms for slow and fast light chains)	Influences the contraction velocity of the sarcomere; modulates the kinetics of crossbridge cycling
Structural	
Nebulin	Anchors actin to Z discs
Titin	Creates passive tension within the stretched sarcomere; acts as molecular "springs"
Desmin	Helps to stabilize the longitudinal and lateral alignment of adjacent sarcomeres
Vimentin	Helps maintain periodicity of Z discs
Skelemin	Helps stabilize the position of M lines
Dystrophin	Provides structural stability to the cytoskeleton and sarcolemma of the muscle fiber
Integrins	Stabilizes the cytoskeleton of the muscle fiber

---continue Structure of Skeletal Muscle

➢ Structural Basis for Muscle Contraction and Relaxation

- Length of each serially repeating sarcomere unit is approximately 2.5 µm when the muscle is relaxed
- Length of each sarcomere decreases to about 1.5µm when the muscle is fully contracted
- Sarcomere unit may be increased to about 3.0µm when the muscle is stretched
- Sarcomere is bounded on each end by a Z line
- Widths of individual A bands do not change during contraction
- I band, however, does become more narrow, and the H zone within the A band is obliterated
- Muscles contract by the free ends of the actin filaments sliding toward each other into the central H zone of the A bands
- Z lines are pulled closer together so that the I bands shorten

---continue Structure of Skeletal Muscle



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- Although the amount of shortening of each sarcomere unit is small, for example, 0.5 to 1.0 µm, the shortening of several thousands of sarcomere units linked in series can produce a reduction of several centimeters in the overall length of the muscle
- Muscle fiber 10 cm in length (such as many fibers in the biceps brachii muscle of adults) would have approximately 40,000 sarcomere units lined up end to end
- If each of the 40,000 sarcomere units were shortened by 1µm, the ends of the entire muscle fiber 40,000 µm (or 4 cm) closer together
- Actin and myosin filaments slide past each other during muscle contraction is sliding filament theory

Muscle Fiber Types

Type I	• slow-twitch, tonic, or slow oxidative (SO)
Type II A	• fast oxidative-glycolytic (FOG)
Type II B	• fast-twitch, phasic or fast glycolytic (FG)

---continue Muscle Fiber Types

- **Type I: Slow-twitch, tonic, or slow oxidative (SO)**
- Dark (like the dark meat of a chicken)
- Contains large numbers of mitochondria and a high concentration of myoglobin (muscle hemoglobin that stores oxygen)
- Mitochondria of type I muscle fibers are found to have an abundance of oxidative enzymes associated with aerobic metabolism
- Fatigue-resistant
- Innervated by small diameter axons of the motor nerve and are recruited first in a muscle contraction
- High proportion in postural control muscles (e.g. soleus 85%)
- Low in quick-moving, refined movement muscles (e.g. orbicularis oculi 10%)

---continue Muscle Fiber Types

- Proportion of Type I SO muscles (Descending order)
  1. Soleus
  2. Adductor Pollis
  3. Tibialis anterior
  4. Biceps femoris
  5. Peroneus longus
  6. Deltoid
  7. Gastrocnemius
  8. Biceps brachii
  9. Quadriceps
  10. Sternocleidomastoid
  11. Triceps brachii
  12. Orbicularis occuli

---continue Muscle Fiber Types

- **Type II A: Fast oxidative-glycolytic (FOG)**

- Intermediate in characteristics such as color, numbers of mitochondria, size, speed of contraction, and rate of fatigue

- "Transition" fiber type between slow oxidative Type I and fast glycolytic Type II B

---continue Muscle Fiber Types

- **Type II B: Fast-twitch, phasic or fast glycolytic (FG)**
- Pale (like the white meat of a chicken)
- Contains fewer mitochondria and only small amounts of myoglobin
- Larger in diameter than Type I muscle fibers
- Develop greater force of contraction and complete a single twitch in a significantly shorter time
- Fatigue more quickly
- Mitochondria of Type II B muscle fibers are found to have a preponderance of glycolytic enzymes associated with anaerobic metabolism
- innervated by larger diameter motor axons and are recruited after Type I and Type II A
- E.g. muscles involved in large or quick bursts of activity Biceps brachii

---continue Muscle Fiber Types

TABLE 3-2 | CHARACTERISTICS OF SKELETAL MUSCLE FIBERS BASED ON PHYSICAL AND METABOLIC PROPERTIES

Muscle Fiber Type Property	Type I Slow-Twitch SO	Type IIA Intermediate FOG	Type IIB Fast-Twitch FG
Muscle fiber diameter	Small	Intermediate	Large
Color	Red (dark)	Red	White (pale)
Myoglobin content	High	High	Low
Mitochondria	Numerous	Numerous	Few
Oxidative enzymes	High	Intermediate	Low
Glycolytic enzymes	Low	Intermediate	High
Glycogen content	Low	Intermediate	High
Myosin ATPase activity	Low	High	High
Major source of ATP	Oxidative phosphorylation	Oxidative phosphorylation	Glycolysis
Speed of contraction	Slow	Intermediate	Fast
Rate of fatigue	Slow	Intermediate	Fast

Nerve Fibers

➢ **Peripheral Neurons**

- Different shapes and sizes depending on their location and functions
- Typical neuron consists of;
- Cell body containing the nucleus),
- Dendrites several short radiating processes
- Axon one long process that terminates in twig-like branches and may have branches (collaterals) projecting along its course
- Axon, together with its covering (sheath), forms the nerve fiber
- Large motor and sensory nerves are wrapped with a covering containing a white lipid substance, myelin (insulating material)
- Myelin sheath forms regular indentations (nodes of Ranvier)

---continue Nerve Fibers

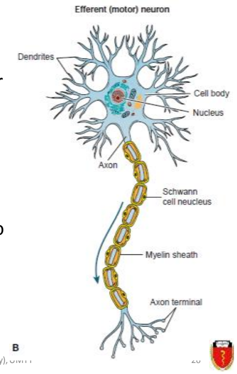
- Classification of Nerve Fibers according to;
  - Function (motor, sensory, autonomic)
  - Axonal diameter
  - Fiber origin (only for sensory fibers)

---continue Nerve Fibers

Classification of Nerve Fibers according to function

➢ **Motor fibers (efferent nerve fibers)**

- Conduct nerve impulses from the spinal cord to skeletal muscle fibers for the control of voluntary muscular activity
- Cell bodies are located in the gray matter of the spinal cord and brain stem
- Lower motor neuron (*final common path* between nervous system and muscular system) is the term used to describe a motor (efferent) nerve whose cell body and axon originate in the ventral horn of the spinal cord and synapse directly onto skeletal muscle.



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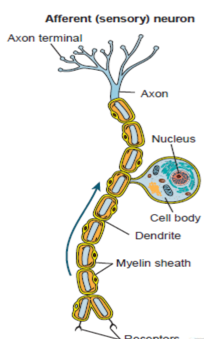
Classification of Nerve Fibers according to function

➢ **Sensory fibers (afferent nerve fibers)**

- Carry impulses arising from various receptors in the skin, muscles, and special sense organs to the CNS, where the impulses are interpreted
- Cell bodies lie in special ganglia



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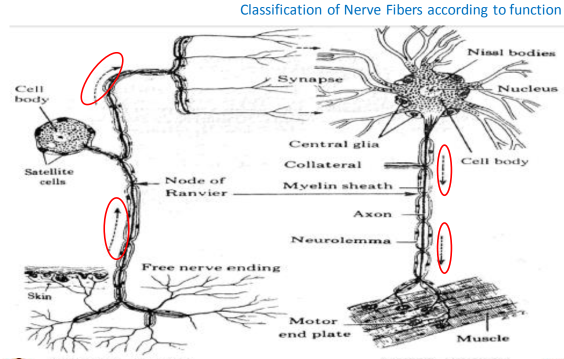
Classification of Nerve Fibers according to function



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Classification of Nerve Fibers according to function

➢ **Autonomic fibers**

- Concerned with the involuntary control of glandular activities and smooth muscles, including smooth muscles surrounding arterioles and venules within muscles

---continue Nerve Fibers

Classification of Motor and Sensory Nerve Fibers on the Basis of Axonal Diameter

- Type A: largest diamteter axons
- Type B: intermediate diameter axons
- Type C: smallest fibers
- A and B fibers are myelinated, C fibers are unmyelinated
- Type A subdivisions include type A-alpha (α), type A-beta (β), type A-gamma (γ), and type A-delta (δ).
- Speed at which a nerve impulse travels along the length of an axon is related to the diameter of the axon.
- Larger axons conduct impulses at a faster velocity.
- Adding a myelin sheath causes the axon to conduct an mpulse even faster

---continue Nerve Fibers

Classification of Motor and Sensory Nerve Fibers on the Basis of Axonal Diameter in the Peripheral Nervous System

TABLE 3–1 | NERVE FIBER TYPES

Fiber Type	Fiber Diameter (µm)	Conduction Velocity (m/sec)	Peripheral Organ	Function
A-alpha (α) (motor)	12–20	70–120	Skeletal muscle	Motor, skeletal muscle efferent
A-alpha Ia (sensory)	12–20	70–120	Muscle spindle afferent	Proprioception
A-alpha Ib (sensory)	12–20	70–120	Golgi tendon organs afferent	Proprioception
A-Beta II (sensory)	5–12	30–70	Muscle spindle and touch/pressure receptors	Touch, pressure, vibration
A-gamma (γ) (motor)	3–6	15–30	Intrafusal muscle fibers of muscle spindle	Motor, muscle spindle efferent
A-delta (δ) (sensory)	2–5	12–30	Skin	Pain and temperature afferent
B fibers	1–3	3–15	Autonomic Sympathetic	Autonomic efferent
C fibers IV	.5–1	.5–2	Skin, autonomic postganglionic	Pain and temperature afferent

---continue Nerve Fibers

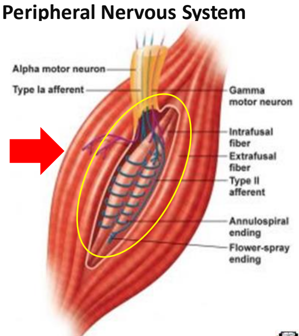
Classification of Sensory Fibers on the Basis of Fiber Origin within the Peripheral Nervous System

Group		Function	
Group I	Ia	carry impulses from muscle spindle primary receptor	Equivalent to A- α fibers
	Ib	carry impulses from Golgi tendon organs (GTO)	
Group II		carry impulses from muscle spindle secondary receptors	Equivalent to A- β fibers

---continue Nerve Fibers

Classification of Motor Fibers on the Basis of Fiber Destination within the Peripheral Nervous System

- Type A-alpha (α) motor neurons innervate **extrafusal** skeletal muscle
- Type A-gamma (γ) motor neurons innervate **intrafusal** (within the spindle) skeletal muscle fibers



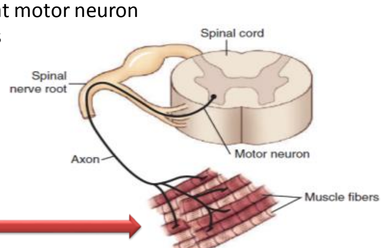
---continue Nerve Fibers

Nerve Fibers in the Central Nervous System (Central Neurons)

- Motor Neurons
  - Upper motor neurons
  - Lower motor neurons
  - Interneurons
- Sensory Neuron
  - 1st order neurons
  - 2nd order neurons
  - 3rd order neurons

Motor Unit

- **What is motor unit?**
- Individual motor neuron (majority are A alpha, but not all) together with its axon and all of muscle fibers that are innervated by that motor neuron
- Motor commands travel from the neuronal cell bodies over peripheral nerve fibers and then across the neuromuscular junction.



---continue Motor Unit

- Number of muscle fibers innervated by a single motor nerve fiber varies from
- As few as five, as in some of the eye muscles
- As many as 1,000 or more, as in large muscles such as the gastrocnemius

innervation ratio → average number of muscle fibers per motor unit in a given muscle

innervation ratio → $\frac{\text{number of muscle fibers}}{\text{Number of large motor axons}}$

---continue Motor Unit

- The term "motor unit" implies, all muscle fibers within a given motor unit act as one unit, contracting or relaxing nearly simultaneously.
- Muscle fibers of one motor unit are not adjacent to one another; they are distributed throughout the muscle's length.
- If the nerve activates the muscle fibers of a motor unit sufficiently that the muscle fibers contract, those fibers will contract maximally
- Principle is known as all-or-none law,
- The law applies only to individual motor units

---continue Motor Unit

Gradation of Strength of Muscle Contraction

- Three different principles

Size principle → Smallest motor units are activated first. Largest motor neurons are recruited last

Recruitment principle → Increasing number of motor units activated simultaneously increases overall muscle tension.

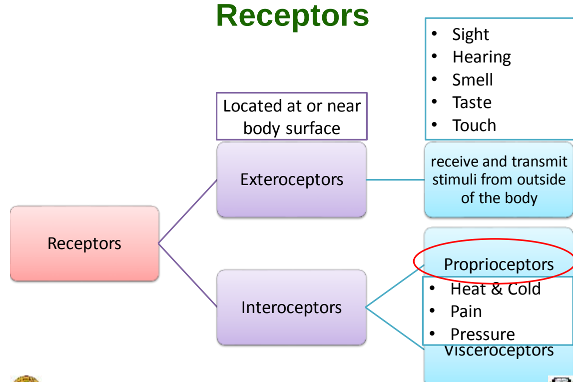
Excitatory input/rate coding principle → Increasing frequency of stimulation of individual motor units increases percentage of time that each active muscle fiber develops maximum tension

---continue Motor Unit

TABLE 3-3 | NUMBER OF MOTOR UNITS, MOTOR FIBERS, AND MUSCLE SPINDLES PER MOTOR UNIT IN HUMAN MUSCLE

		NUMBER OF MUSCLE FIBERS		NUMBER OF MUSCLE SPINDLES	
Muscle	Number of Motor Axons	Per Muscle × 10^3	Average Per Motor Unit	Per Muscle	Per Motor Unit
Biceps brachii	774	580	750	320	0.4
Brachioradialis	330	130	390	65	0.2
First dorsal interosseus	119	41	340	34	0.3
First lumbrical	98	10	110	53	0.6
Opponens pollicis	133	79	595	44	0.3
Masseter	1020	1000	980	160	0.2
Temporalis	1150	1500	1300	217	0.2
Gastrocnemius medius	580	1000	1720	80	0.1
Tibialis anterior	445	270	610	284	0.6

Receptors



---continue Receptors

➢ **What are proprioceptors?**

- Receptors gather information about one's own joints and joint movements
- Detect changes in tension and position of the structures in which the receptors are situated
- Located in muscles, tendons, joints, capsules, ligaments, fibrous membranes and labyrinth of inner ear
- Stimulated by motion of the body
  - ❖ Joint proprioceptors
  - ❖ Tendon proprioceptors
  - ❖ Muscle proprioceptors

---continue Receptors

Joint, Tendon, and Muscle Receptors

- Specialized receptors are present in joint structures, tendons, and skeletal muscles.
- Receptors detect changes in tension and position of the structures in which the receptors are situated, and a pattern of nerve impulses is generated in the receptor to convey the information to other parts of the nervous system.
- Moment-to-moment changes are relayed to centers in the spinal cord and brain
  - ❖ joint angle (position of the joint),
  - ❖ speed of joint motion,
  - ❖ amount of joint compression or distraction,
  - ❖ changes in muscle length
  - ❖ force of muscle contraction

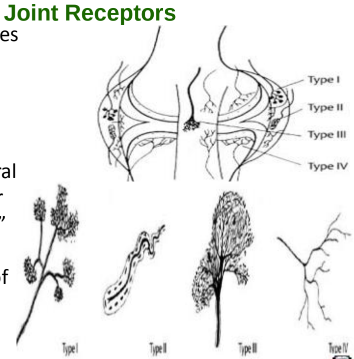
---continue Receptors

- In the CNS, this information is integrated with that coming in from other sensory organs, such as;
  - ❖ retina of the eye (vision)
  - ❖ vestibular apparatus of the inner ear (dealing with balance and position sense)
- Integrated sensory signals then are used by motor control centers in the brain to automatically adjust location, type, number, and frequency of motor unit activation
- So that appropriate muscle tension is developed to perform desired movements

---continue Receptors

Joint Receptors

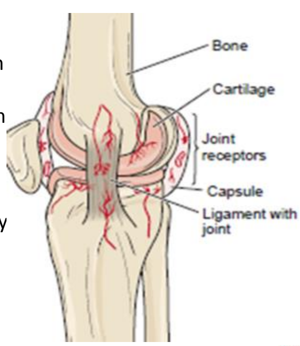
- Several different types of sensory receptors are in joint capsules and ligaments.
- Most of these receptors emit several action potentials per second as a "resting" output, so the body always has a sense of position in space.



---continue Receptors

Joint Receptors

- The receptor is stimulated when it is deformed.
- Depending on the location and magnitude of deforming forces acting on the joint and receptor location, certain receptors are stimulated and discharge a high-frequency burst of nerve impulses when the joint moves.



---continue Receptors

Joint Receptors

- Receptors typically adapt, which means that the frequency of impulses decreases after movement ceases and then transmit a steady train of nerve impulses thereafter.
- Further movement of the joint may cause one set of receptors to stop discharging impulses and another set to become active.
- Information from joint receptors continually provides feedback information to the nervous system to apprise the nervous system of momentary angulation of joints and of the rate of movement of joints.

---continue Receptors

Golgi Tendon Organs

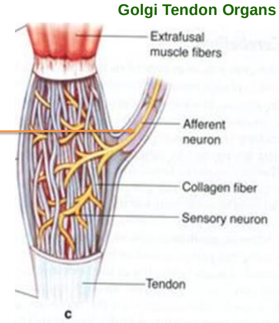
- Gotgi tendon organs (GTOs) lie within muscle tendons near the point of attachment of the muscle fiber to the tendon
- An average of 10 to 15 muscle fibers is usually connected in direct line (series) with each GTO
- GTO is stimulated by tension produced by the Small bundle of muscle fibers

- ideally suited to detect force or tension in either muscle or tendinous collagen fibers but not changes in muscle

---continue Receptors

Golgi Tendon Organs

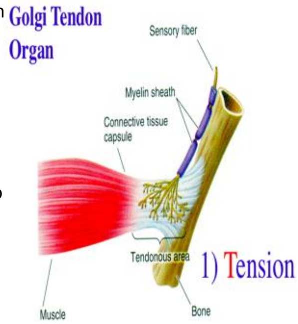
- Nerve impulses discharged by the tendon organ are transmitted over large, rapidly conducting afferent axons (group Ib fibers) to the spinal cord and cerebellum
- Arrival of GTO nerve impulses at the spinal cord excites inhibitory interneurons which, in turn, inhibit the neurons (A α neurons) of the contracting muscle, thus limiting the force developed to that which can be tolerated by the tissues being stressed.



---continue Receptors

Golgi Tendon Organs

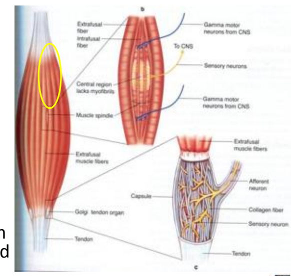
- Slips of tendon, however, can be torn free from natural points of attachment by the abrupt application of a forceful contraction or by abrupt passive stretch of the tissues.
- Therefore, to avoid injury, a muscle should be activated o stretched to a moderate degree at first, and then a gradual increase in the force exerted on the points of attachment may occur.



---continue Receptors

Muscle Spindles

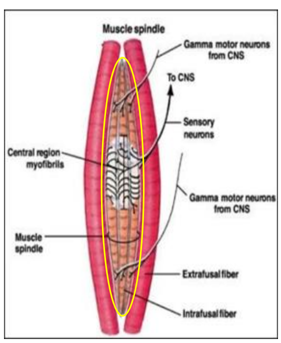
- Skeletal muscles are composed of **extrafusal** (L. *extra,* outside of or in addition, plus *fusus,* spindle) **fibers,** which are "regular" or skeletal muscle fibers**.**
- **Muscle spindles** are lying within muscles, parallel to the extrafusal fibers
- Lengths of human muscle spindles vary from 0.5 to 13 mm, but the usual length is 2 to 4 mm
- Muscle spindles are fusiform in shape (widest in the center and tapering toward each end)



---continue Receptors

Muscle Spindles

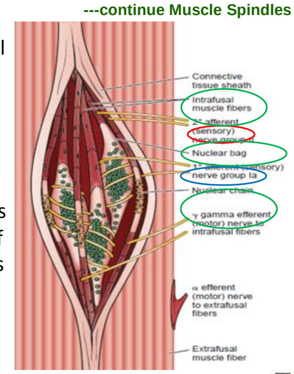
- Spindles are present in almost all muscles but are most numerous in the muscles of the arms and legs
- A muscle spindle is composed of sets of 3 to 10 small muscle fibers called **intrafusal muscle fibers (IFMF)**
- **Intrafusal muscle fibers** are encapsulated within a connective tissue sheath



---continue Receptors

---continue Muscle Spindles

- Two types of morphological arrangements of the intrafusal fiber nuclei: nuclear bag and nuclear chain fibers
- Encapsulated systems are attached at their polar ends to the connective tissues of the extrafusal fiber bundles
- Muscle spindles have both afferent and efferent innervation



---continue Receptors

Muscle Spindles

- Muscle spindles function as a stretch receptor, sending sensory impulses over afferent axons that "inform" other neurons in the spinal cord and brain of the length of muscle spindle and of the rate at which muscle stretch is occurring
- Muscle spindles also contain contractile fibers that are controlled by nerve impulses reaching them via small-diameter motor axons (efferent, type A-γ motor neurons) from the spinal cord

---continue Receptors

Muscle Spindles

Stretch Receptors
- Primary/ annulospiral (AS) ending — sensitive to both tonic and phasic response
  - Nuclear bag and Nuclear chain fibers
- Secondary/ flower spray (FS) ending — sensitive to tonic response only
  - Nuclear chain fibers

---continue Receptors

Muscle Spindles

- Degree of shortening of the contractile portions of the muscle spindle regulates the sensitivity of the stretch receptor portion of the muscle spindle
- α motor neurons stimulate the contraction of extrafusal fibers, γ motor neuron discharge causes contraction of intrafusal fibers
- Contraction of the intrafusal fibers provides for an adjustable sensitivity range for changing lengths of the muscle

---continue Receptors

Muscle Spindles

- Middle, noncontractile part of the muscle spindle can be stretched by two different types of mechanisms

entire skeletal muscle is stretched → spindle also is stretched

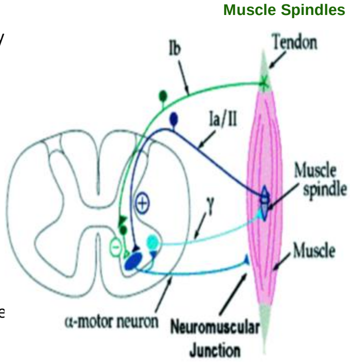
contractile portions at each end of the muscle spindle are activated by impulses arriving over gamma motor nerves → contractile portions shorten, thereby stretching central bag portion of spindle

stretch of nuclear bag portion of muscle spindle →
- activates primary (Ia) and/or secondary (II) stretch receptors

---continue Receptors

Muscle Spindles

- Activation of the sensory receptors increases the frequency of nerve impulses emitted from the receptors.
- Afferent nerves (group Ia) from the primary receptor make synaptic connections with higher brain centers and with the motor neurons (A α motor neurons) that control extrafusal muscle fibers in the same muscle.



---continue Receptors

Muscle Spindles

Abrupt stretch of muscle

Initiates a burst of impulses from primary stretch receptor in muscle fiber

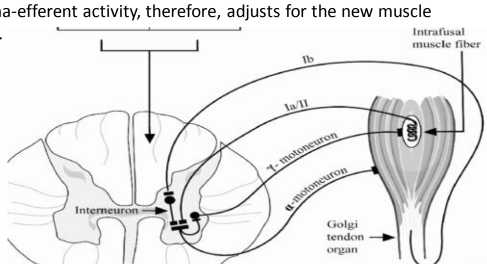
Travels to spinal cord

Excites activity in motor units of the same muscle

---continue Receptors

Muscle Spindles

- Shortening of the muscle as a whole relieves stretch on the muscle spindles contained in the muscle, thereby temporarily removing the stimulus from the stretch receptors.
- Gamma-efferent activity, therefore, adjusts for the new muscle length.

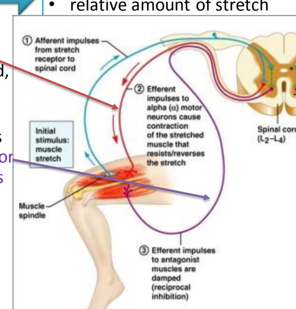


---continue Receptors

Muscle Spindles

Primary sensory endings → detect →
- velocity of stretch
- relative amount of stretch

- Arrival of impulses from primary receptor excites α motor neurons in spinal cord, innervating muscle fibers in stretched muscle
- Impulses excite interneurons which, in turn, inhibit α motor neurons to opposite muscles of the stretched muscle
- Such inhibition promotes relaxation of the opposing muscle so that it can be elongated easily while the contracting muscle shortens



---continue Receptors

Muscle Spindles

- Stretching elbow toward extension places a stretch on elbow flexors (biceps brachii muscle)

stretched elbow flexor (biceps muscle)
- excitation of motor units in elbow flexor (biceps muscle)
- inhibition of motor units in elbow extensor triceps muscle)

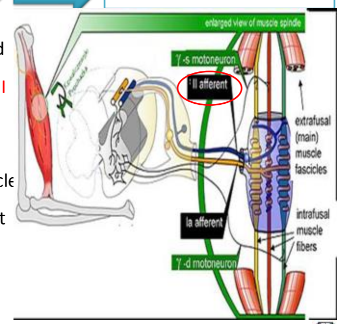
- Afferent fibers from muscles also send their transduced information of muscle movement to higher centers in the CNS for proprioceptive integration.

---continue Receptors

Muscle Spindles

Secondary sensory endings → detect → • amount of stretch

- Signals from secondary receptors are transmitted over smaller-diameter afferent neurons (group II fibers), which synapse principally with interneurons and elicit more delayed and more variable patterns of muscle reflexes than the reflex obtained from the output of primary receptors.
- Signals from secondary sensory endings also are relayed to higher regions of the CNS.



---continue Receptors

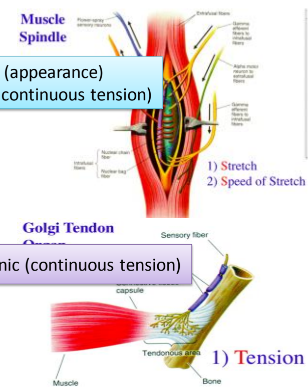
Muscle Spindles

- Summary of Muscle Spindle Functions
- Muscle spindles function as "comparators"
- Comparing length of spindle with that surround spindlelength of skeletal muscle fibers
- If the length of surrounding extrafusal muscle fibers is less than that of the spindle, frequency of nerve impulses discharged from receptors is reduced.
- When central portion of spindle is stretched because of γ-efferent activity, its sensory receptors discharge more nerve impulses, which reflexly excite α motor neurons to activate extrafusal muscle fibers.

❖ The mechanism is particularly important in the regulation of postural muscle tone.

---continue Receptors

- Primary stretch receptor signals both velocity of stretch and length of muscle spindle.
  - Phasic (appearance)
  - Tonic (continuous tension)
- Secondary stretch receptor signals length of muscle spindle.
- GTO detects amount of tension being exerted by muscle fibers
  - Tonic (continuous tension)



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THANK YOU