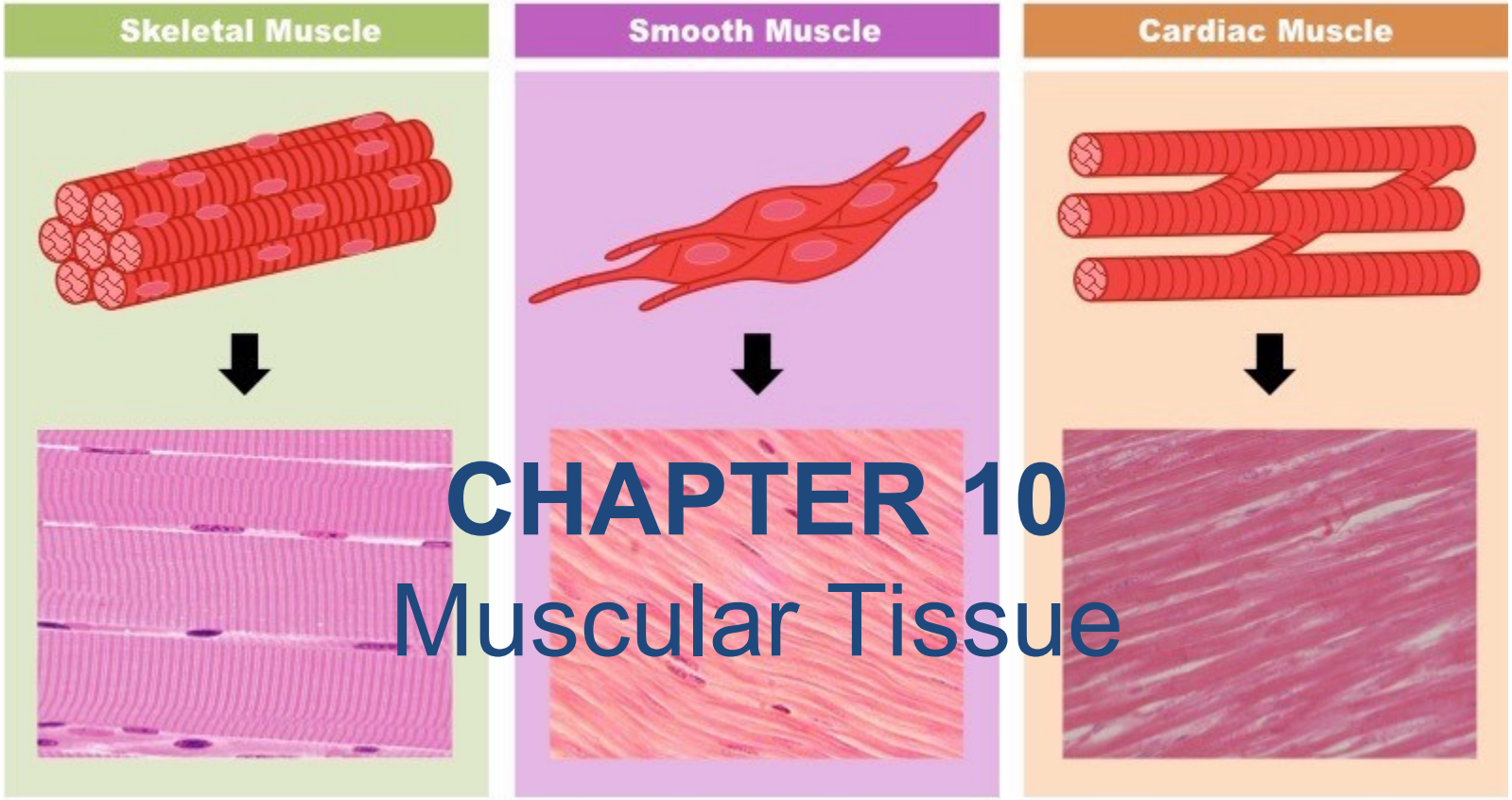

CHAPTER 10
Muscular Tissue

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Muscle Tissue

Anatomy Overview

- Muscle Tissue

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Introduction

- **Myology:** the study of the structure, arrangement, and action of muscles.
- Muscular tissue accounts for 40 to 50% of total body mass.

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Overview of Muscular Tissue

- There are three types of muscular tissue:
  - Skeletal
  - Cardiac
  - Smooth

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Functions of Muscular Tissue

- Producing body movements
- Stabilizing body positions
- Storing and moving substances
- Producing heat

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Properties of Muscular Tissue

- **Electrical excitability:** potentials are generated by the passive diffusion of ions such as Na^{+}, K^{+}, Ca^{2+} and Cl^{-} through highly selective molecular pores in the cell surface membrane called ion channels

- **Contractility:** is the ability of muscle cells to forcefully shorten

- **Extensibility:** is the ability to be extended or stretched.

- **Elasticity:** is the ability to recoil or bounce back to the **muscle's** original length after being stretched

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Structure of a Skeletal Muscle

- **A skeletal muscle bundle:** consists of a body (belly) connected by tendons to the skeleton.
- **Tendon:** or sinew is a tough band of fibrous connective tissue that connects muscle to bone and is capable of withstanding tension. Tendons are similar to ligaments; both are made of collagen. Ligaments connect one bone to another, while tendons connect muscle to bone
- **Aponeuroses:** a sheet of pearly white fibrous tissue that takes the place of a tendon in flat muscles having a wide area of attachment.

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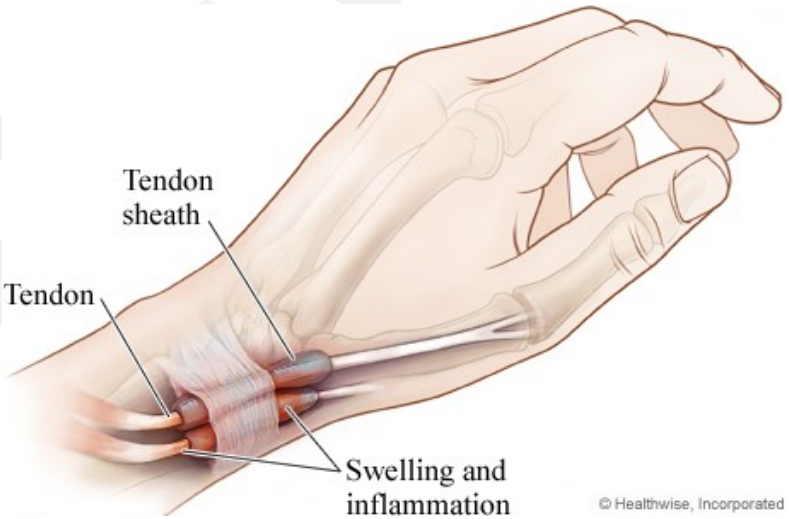
Clinical Connection

- **Tenosynovitis:** is the inflammation of the fluid-filled sheath (called the synovium) that surrounds a tendon, typically leading to joint pain, swelling, and stiffness. Tenosynovitis can be either infectious or noninfectious



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Connective Tissue Coverings

- **Endomysium:** meaning within the muscle, is a wispy layer of areolar connective tissue that ensheaths each individual myocyte (muscle fiber, or muscle cell). It also contains capillaries and nerves
- **Perimysium**: the sheath of connective tissue surrounding a bundle of muscle fibers
- **Epimysium** is connective tissue that wraps the whole muscle. Fascia (or "deep fascia") is a layer of thickened connective tissue that covers the entire muscle and is located over the layer of epimysium

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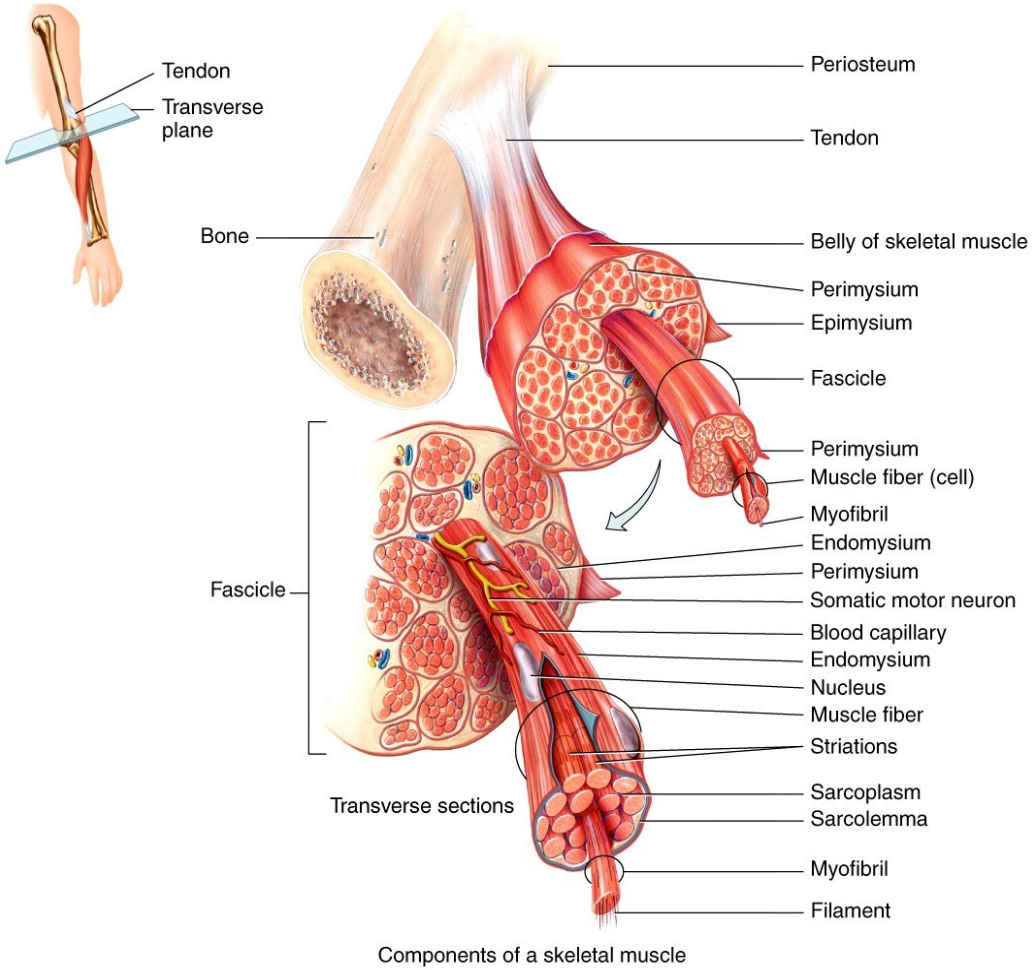
Organization of Skeletal Muscle and Connective Tissue Coverings



Components of a skeletal muscle

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Clinical Connection

- **Fibromyalgia** is a disorder characterized by widespread musculoskeletal pain accompanied by fatigue, sleep, memory and mood issues. Researchers believe that fibromyalgia amplifies painful sensations by affecting the way your brain processes pain signals

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Nerve and Blood Supply

- **Neurovascular bundle:** is a structure that binds nerves and veins (and in some cases arteries and lymphatics) with connective tissue so that they travel in tandem through the body

- **Somatic motor neurons:** originate in the central nervous system, project their axons to skeletal muscles (such as the muscles of the limbs, abdominal, and intercostal muscles), which are involved in locomotion

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Microscopic Anatomy of a Skeletal Muscle Fiber (Cell)

- **Muscle fibers:** or muscle cells, are formed from the fusion of developmental myoblasts in a process known as myogenesis. Muscle fibers are cylindrical and have more than one nucleus. They also have multiple mitochondria to meet energy needs. Muscle fibers are in turn composed of myofibrils
- **Hypertrophy:** is an increase and growth of muscle cells. Hypertrophy refers to an increase in muscular size achieved through exercise
- **Hyperplasia:** the enlargement of an organ or tissue caused by an increase in the reproduction rate of its cells, often as an initial stage in the development of cancer.

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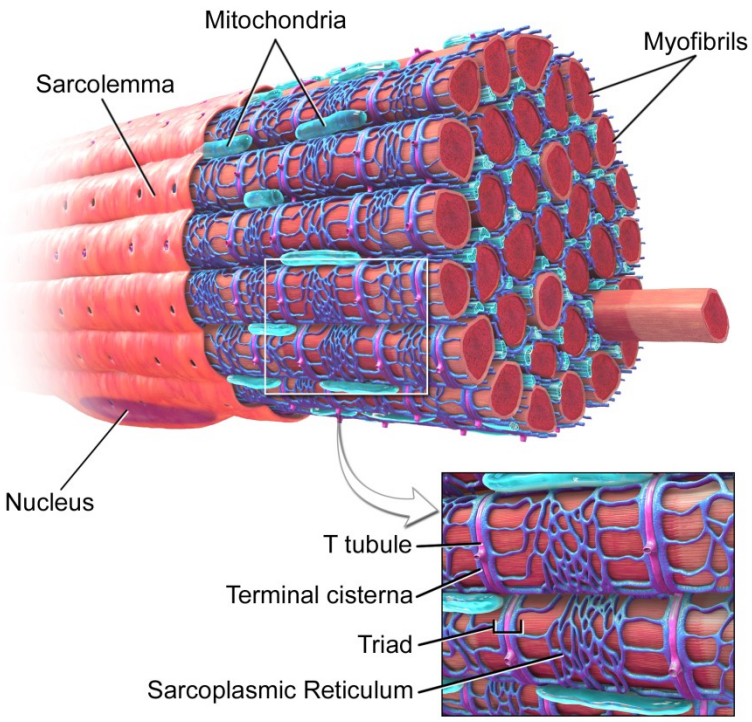
Microscopic Anatomy

- **Sarcolemma:**the fine transparent tubular sheath which envelops the fibers of skeletal muscles.

- **Transverse tubules (T tubules):** are extensions of the cell membrane that penetrate into the centre of skeletal and cardiac muscle cells. … Although these structures were first seen in 1897, research into T-tubule biology is ongoing.

- **Sarcoplasm:** the cytoplasm of striated muscle cells



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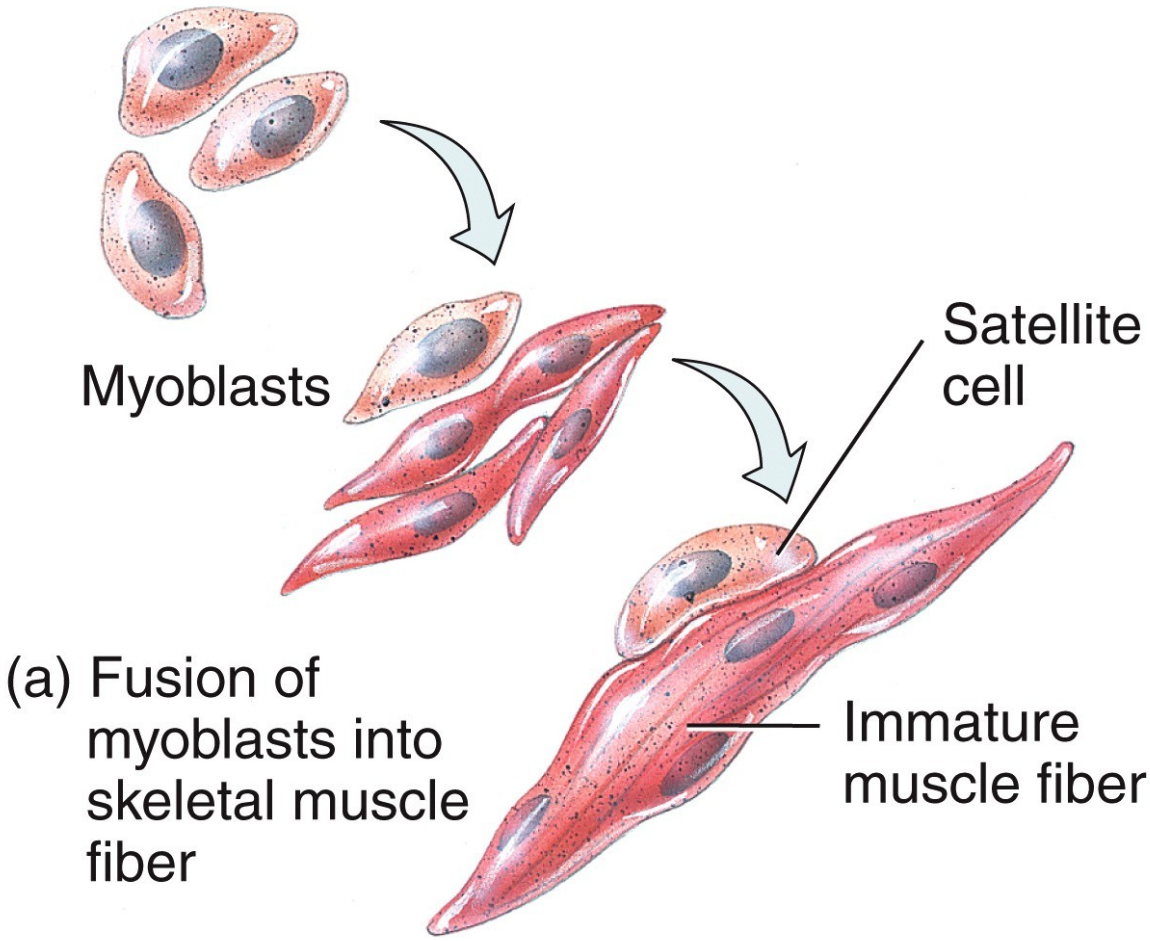
Microscopic Organization of Skeletal Muscle



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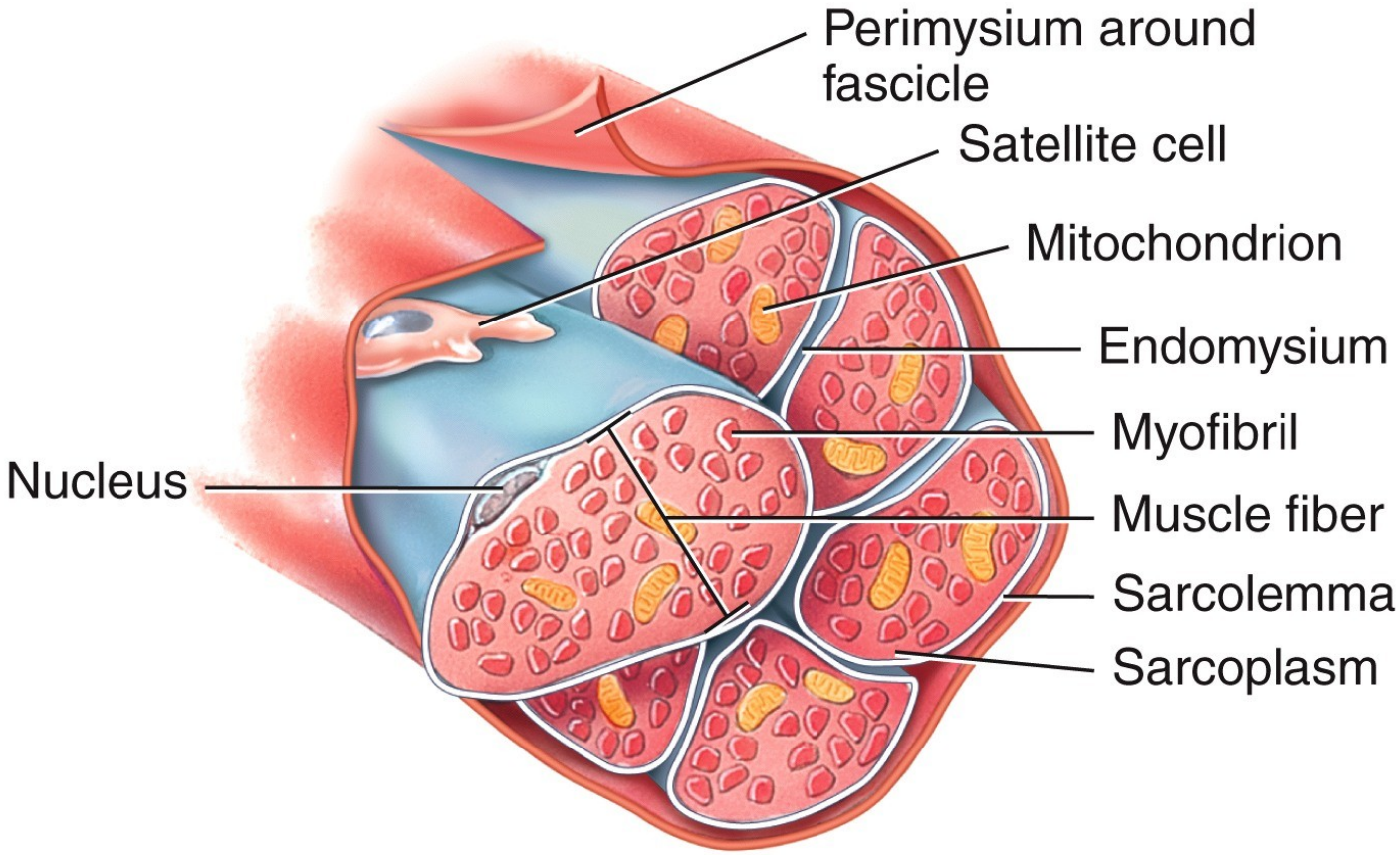
Microscopic Organization of Skeletal Muscle



(b) Organization of a fascicle

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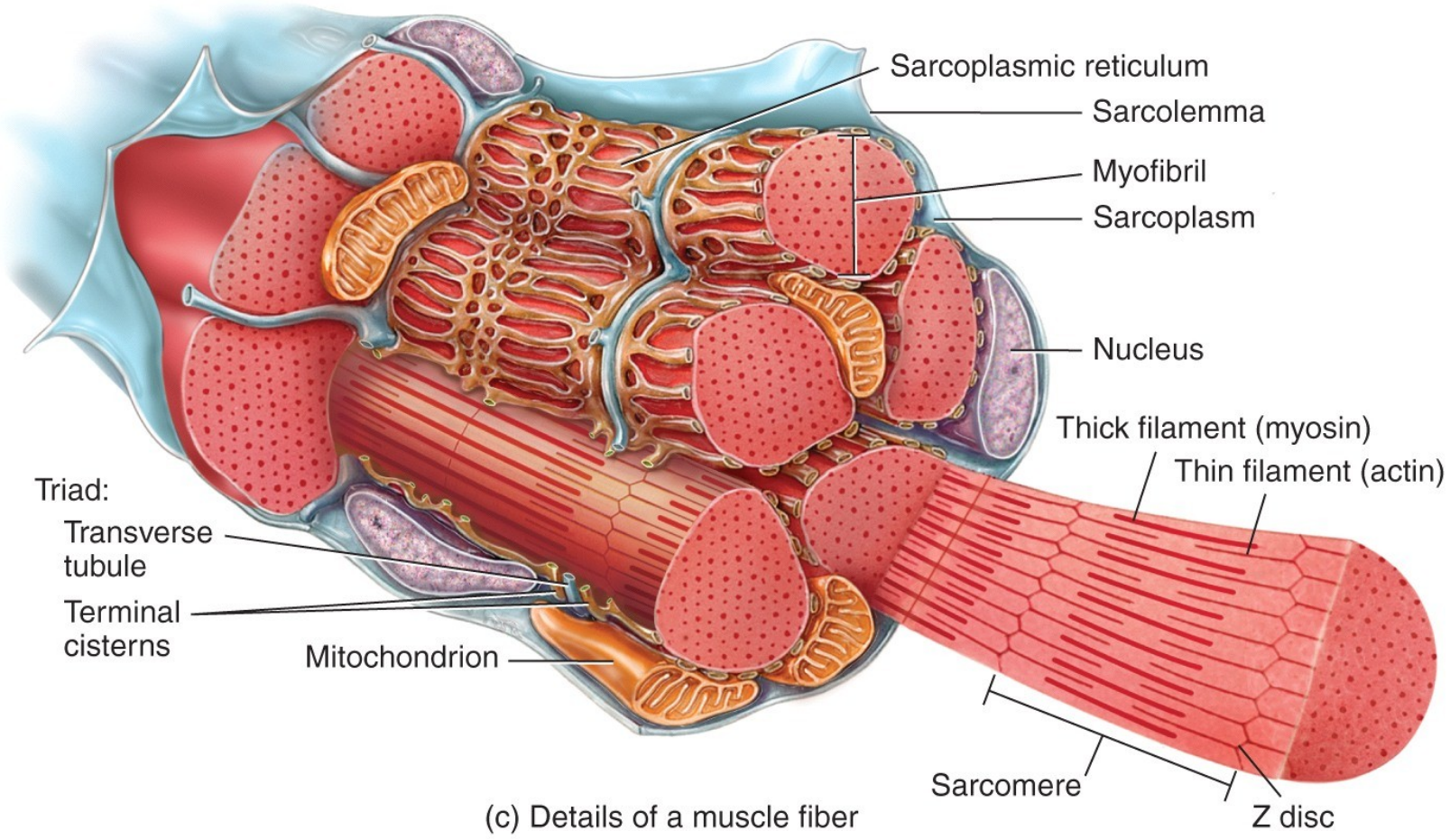
Microscopic Organization of Skeletal Muscle



(c) Details of a muscle fiber

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Microscopic Anatomy

- **Myofibrils:** any of the elongated contractile threads found in striated muscle cells.
- **Sarcoplasmic reticulum (SR)**
  - is a membrane-bound structure found within muscle cells that is similar to the endoplasmic reticulum in other cells. The main function of the SR is to store calcium ions (Ca^{2+})

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Filaments and the Sarcomere

- Myofibrils are made of thick filaments and thin filaments, which in turn are made of protein.
- The filaments are arranged in compartments called sarcomeres.
- The pattern of overlap of thick and thin filaments consists of zones and bands, which cause the striated appearance of skeletal muscle.

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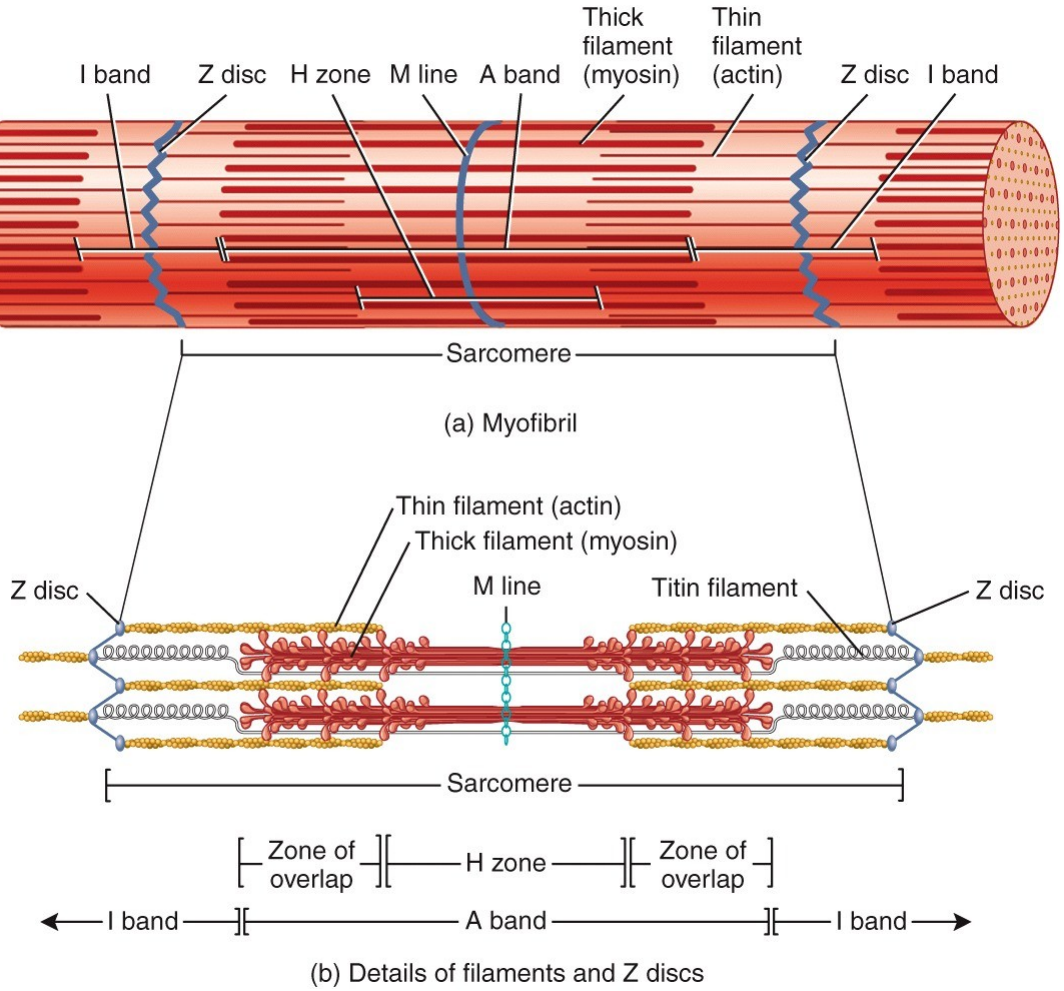
The Arrangement of Filaments Within a Sarcomere



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Clinical Connection

- **Muscular atrophy:** is when muscles waste away. It's usually caused by a lack of physical activity. When a disease or injury makes it difficult or impossible for you to move an arm or leg, the lack of mobility can result in muscle wasting

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Components of a Sarcomere

- Z discs
- A band
- I band
- H zone
- M line

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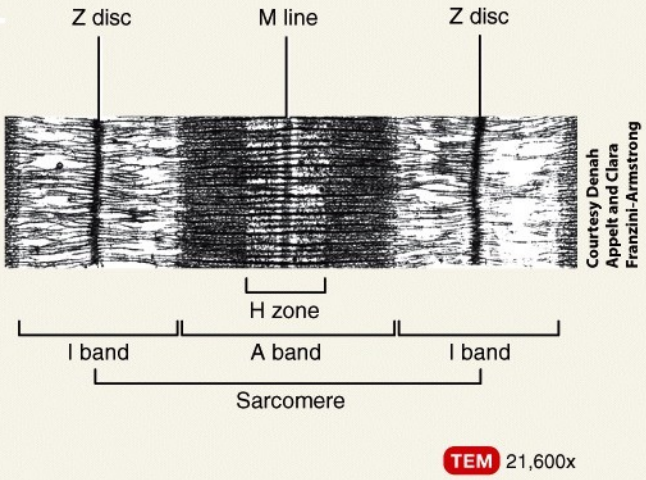
Components of a Sarcomere

TABLE 10.1

Components of a Sarcomere

COMPONENT	DESCRIPTION
Z discs	Narrow, plate-shaped regions of dense protein material that separate one sarcomere from the next
A band	The dark, middle part of the sarcomere that extends the entire length of the thick filaments and also includes those parts of the thin filaments that overlap with the thick filaments
I band	The lighter, less dense area of the sarcomere that contains the rest of the thin filaments but no thick filaments
	A Z disc passes through the center of each I band
H zone	A narrow region in the center of each A band that contains thick filaments but no thin filaments
M line	A region in the center of the H zone that contains proteins that hold the thick filaments together at the center of the sarcomere



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Muscle Proteins

- Myofibrils are built from three kinds of proteins:
  - **Contractile proteins:** are myosin and actin, which form the thin and thick filaments that control the skeletal muscle contraction and relaxation
  - **Regulatory proteins:** troponin and tropomyosin, that are necessary for muscle contraction to occur
  - **Structural proteins:**Titin, myomesin, nebulin, and dystrophin are key structural proteins.

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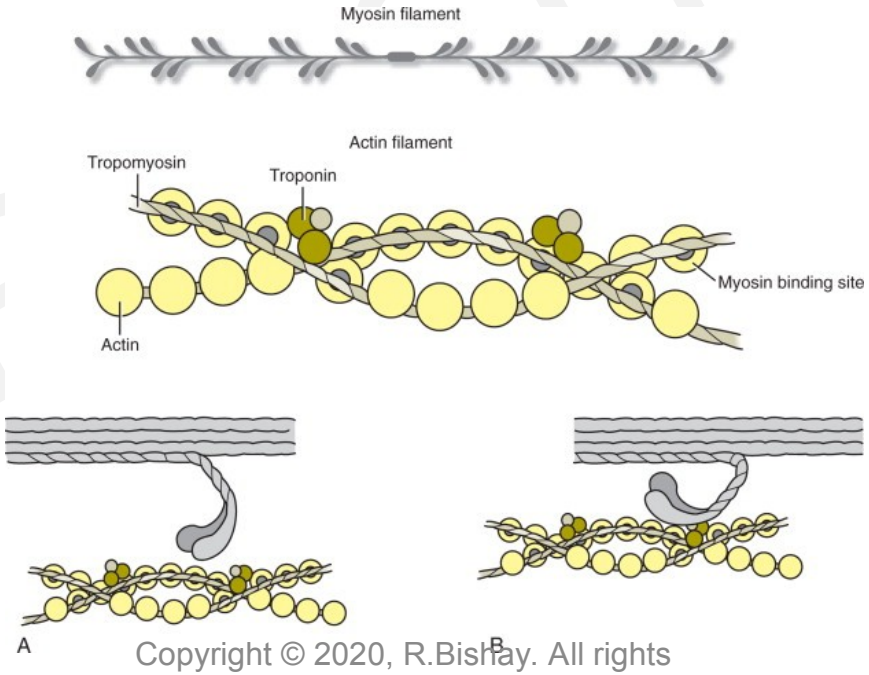
Muscle Proteins

- **Contractile proteins**
  - Myosin is the major component of thick filaments.
  - Actin is the major component of thin filaments.



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Muscle Proteins – Structural

- **Structural proteins**
  - Titin, myomesin, nebulin, and dystrophin are key structural proteins.
  - *E.g.:* ***Titin*** *also known as connectin, is a protein that is encoded by the TTN gene in humans. ... The protein contributes to force transmission at the Z line and resting tension in the I band region. It limits the range of motion of the sarcomere in tension, thus contributing to the passive stiffness of muscle*
  - **Myomesin** is an end line protein that is part of the M line. It is a protein found in the M-band of muscle sarcomeres in association with M-protein. ... It may function as a molecular spring that protects the sarcomere and keeps it stable during intense or sustained stretching

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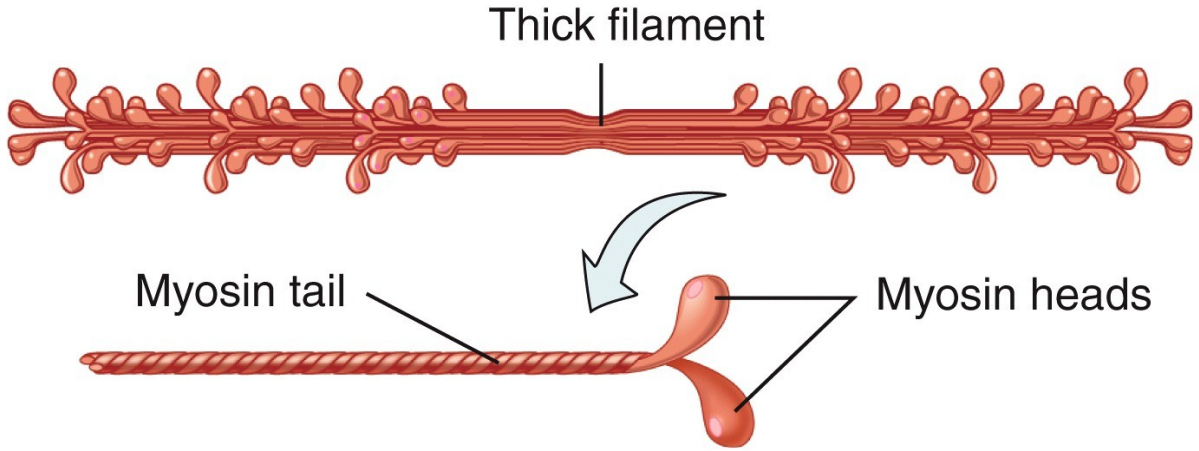
Structure of Thick and Thin Filaments



(a) A thick filament and a myosin molecule

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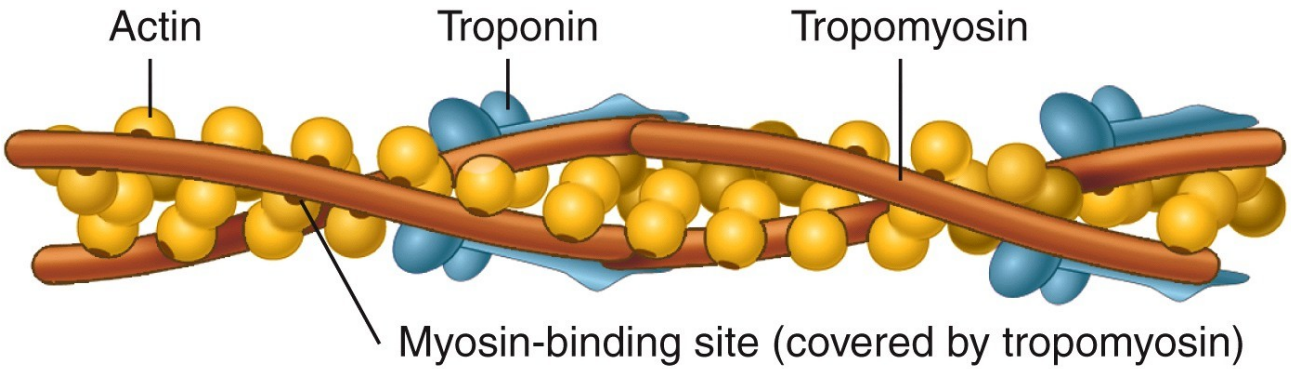

(b) Portion of a thin filament

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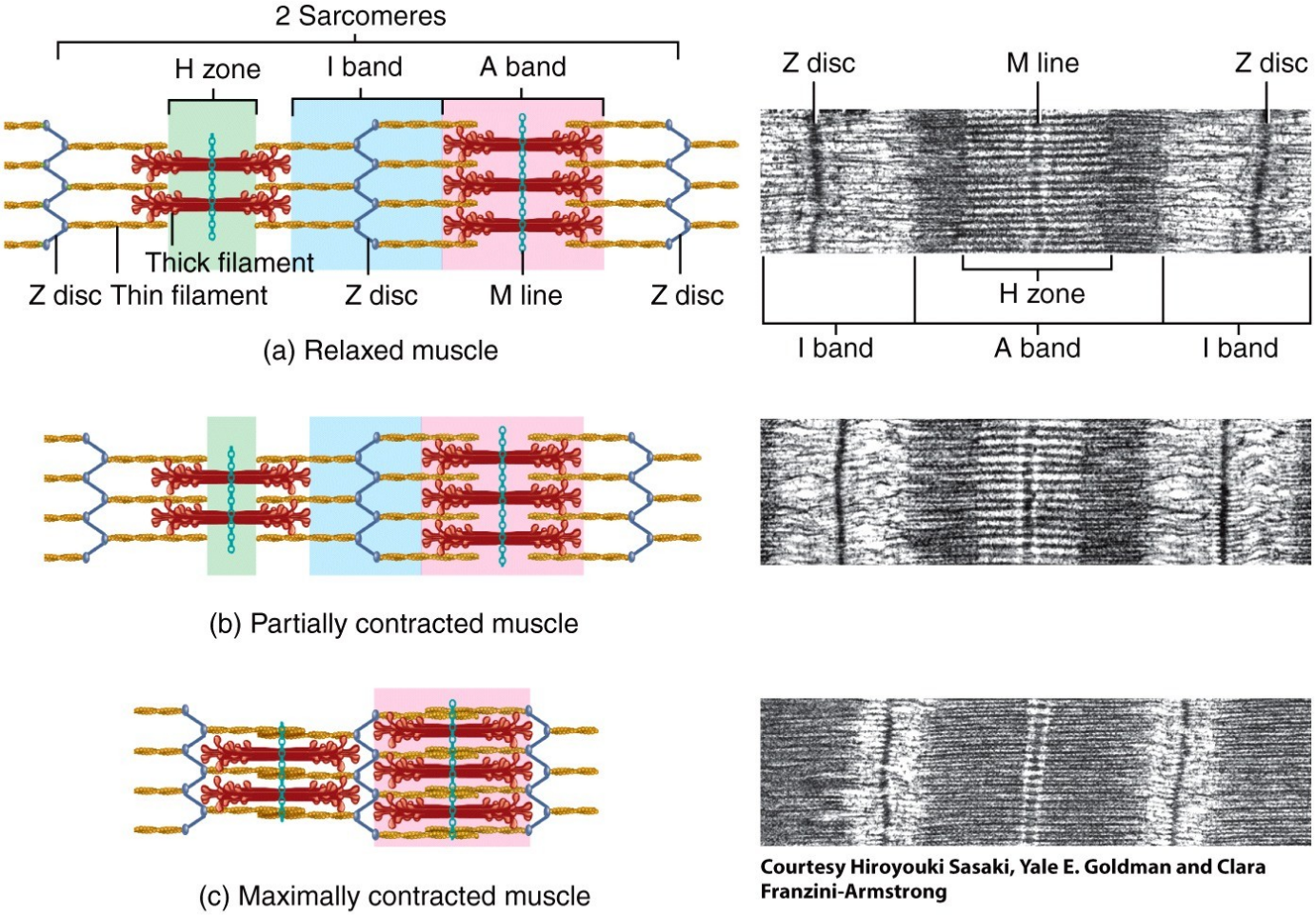
Sliding Filament Mechanism of Muscle Contraction



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The Neuromuscular Junction

- **Synapse:**also called neuronal junction, the site of transmission of electric nerve impulses between two nerve cells (neurons) or between a neuron and a gland or muscle cell (effector). A synaptic connection between a neuron and a muscle cell is called a neuromuscular junction
- **Synaptic cleft:** he space between neurons at a nerve synapse across which a nerve impulse is transmitted by a neurotransmitter. — called also synaptic gap
- **Neurotransmitter:**
- **Axon terminal:**
  - Synaptic end bulb
  - Synaptic vesicles
  - Acetylcholine (ACh)
- **Motor end plate:** Neuromuscular junctions, also called motor end plates, are specialised chemical synapses formed at the sites where the terminal branches of the axon of a motor neuron contact a target muscle cell

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Neuromuscular Junctions

Interactions Animation

- Neuromuscular Junctions

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Steps of a Nerve Impulse

- Release of ACh
- Activation of ACh receptors
- Production of muscle action potential
- Termination of ACh activity

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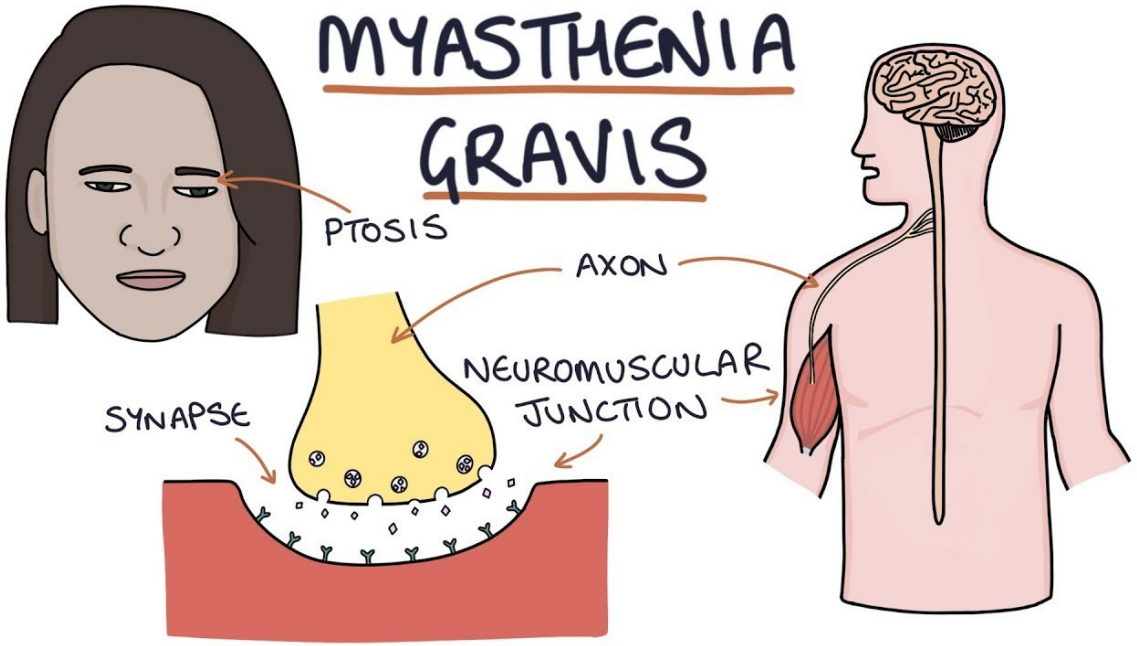
Clinical Connection

- **Myasthenia gravis:** (MG) is a long-term neuromuscular disease that leads to varying degrees of skeletal muscle weakness. The most commonly affected muscles are those of the eyes, face, and swallowing. It can result in double vision, drooping eyelids, trouble talking, and trouble walking. Onset can be sudden



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The Contraction Cycle

- **ATP hydrolysis:** is the catabolic reaction process by which chemical energy that has been stored in the high-energy phosphoanhydride bonds in adenosine triphosphate (**ATP**) is released by splitting these bonds, for example in muscles, by producing work in the form of mechanical energy

- **Attachment of myosin to actin to form cross-bridges: Cross bridging**

- **Power stroke:** occurs when ATP is hydrolyzed to ADP and phosphate. The power stroke occurs when ADP and phosphate dissociate from the myosin head. The power stroke occurs when ADP and phosphate dissociate from the actin active site

- **Detachment of myosin from actin**

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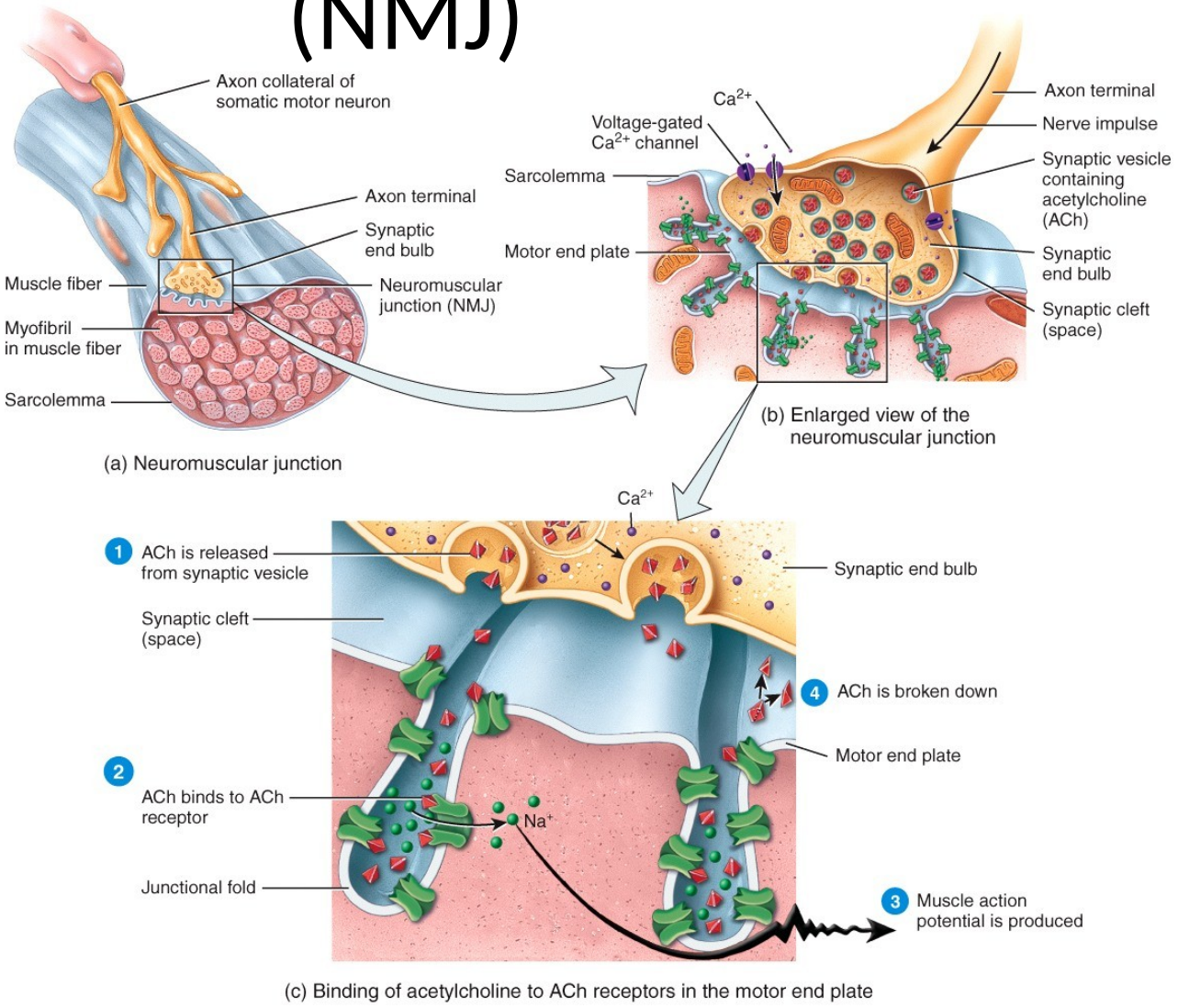
Structure of Neuromuscular Junction (NMJ)



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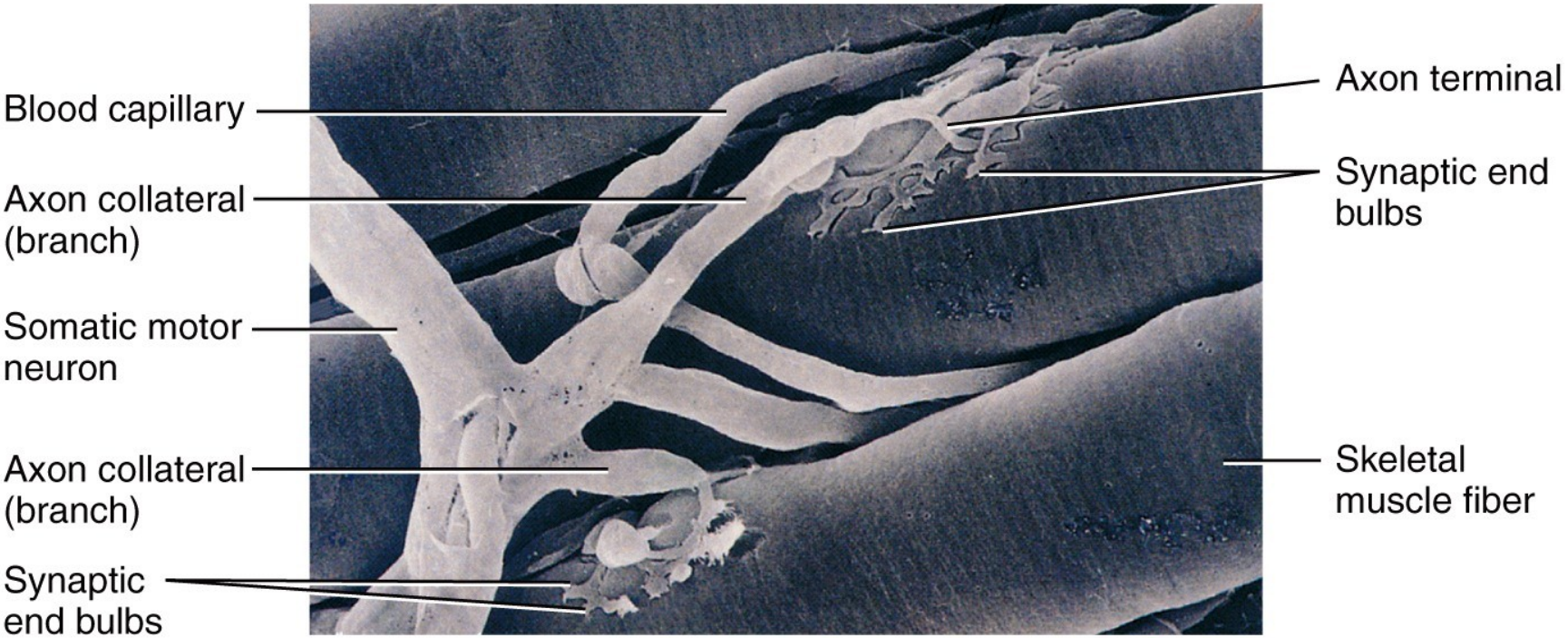
Structure of Neuromuscular Junction (NMJ)



(d) Neuromuscular junction

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Contraction of Skeletal Muscle Cells

Interactions Animation

- Contraction of Skeletal Muscle Cells

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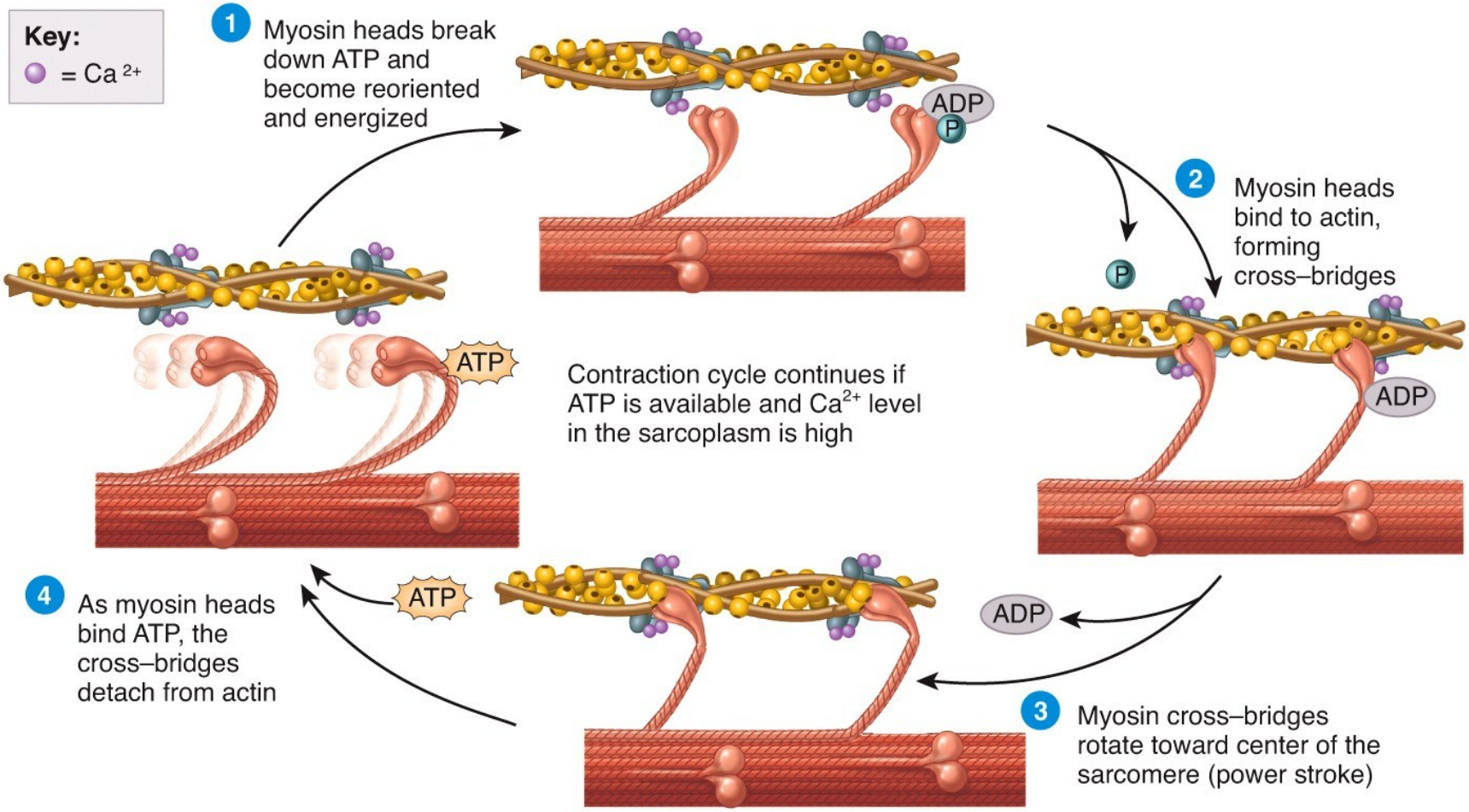
The Contraction Cycle



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Clinical Connection

- **Electromyography:** the recording of the electrical activity of muscle tissue, or its representation as a visual display or audible signal, using electrodes attached to the skin or inserted into the muscle.

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Excitation–Contraction Coupling

- **Ca^{2+} release channels**
- **Excitation–contraction coupling:** is the process by which an electrical stimulus triggers the release of calcium by the sarcoplasmic reticulum, initiating the mechanism of muscle contraction by sarcomere shortening
- **Ca^{2+} active transport pumps:** They are responsible for the active transport of calcium out of the cell for the maintenance of the steep Ca^{2+} electrochemical gradient across the cell membrane.
- **Calsequestrin:** is a calcium-binding protein that acts as a calcium buffer within the sarcoplasmic reticulum. The protein helps hold calcium in the cisterna of the sarcoplasmic reticulum after a muscle contraction, even though the concentration of calcium in the sarcoplasmic reticulum is much higher than in the cytosol

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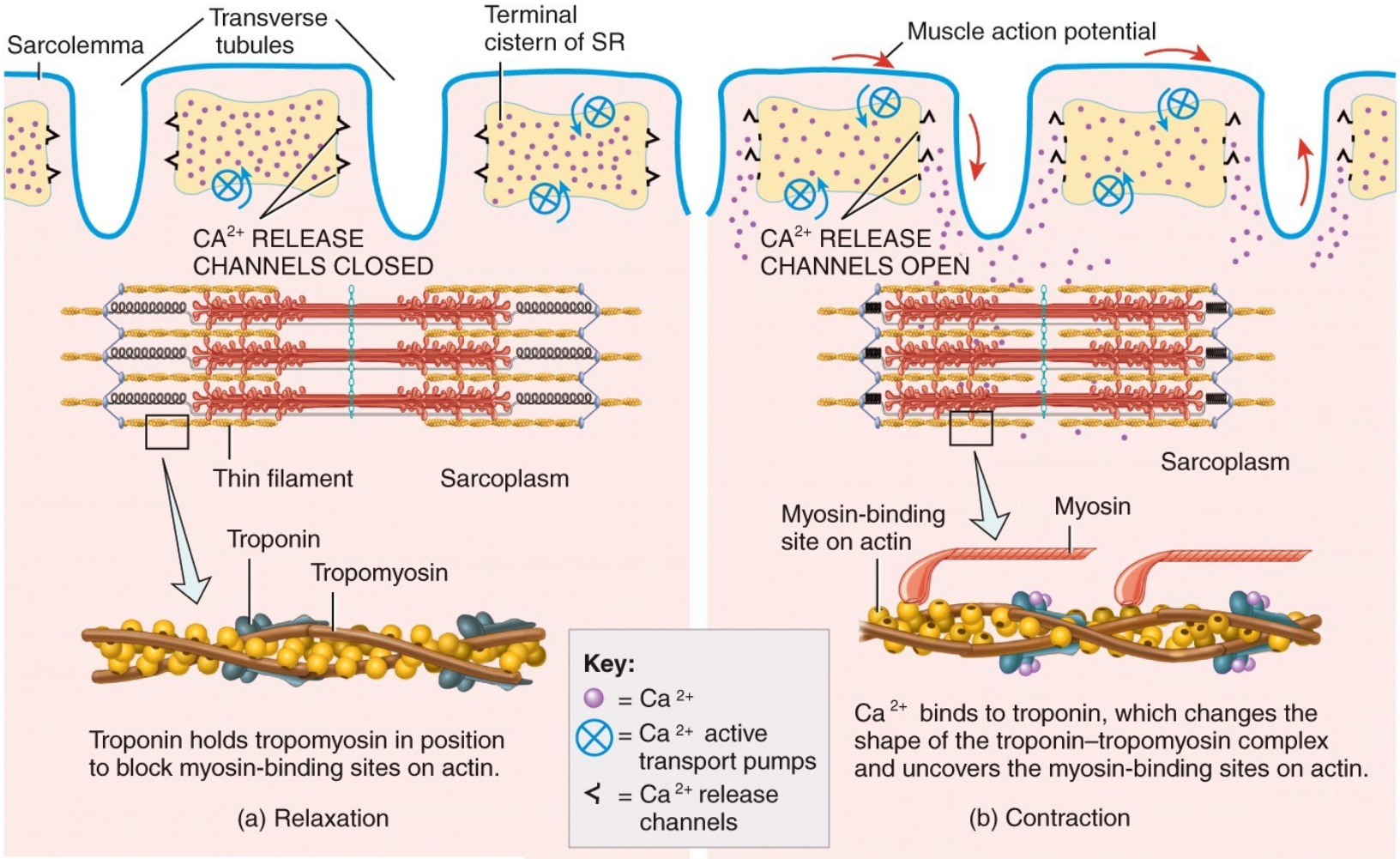
The Role of Ca^{2+} in the Regulation of Contraction by Troponin and Tropomyosin



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Control of Muscle Tension

Interactions Animation

- Control of Muscle Tension

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Muscle Tone

- Even while at rest, a skeletal muscle exhibits muscle tone.
  - Isotonic contraction
  - Isometric contraction

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Muscle Metabolism

Interactions Animation

- Muscle Metabolism

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Isotonic and Isometric Contractions

- **Isotonic contraction**
  - Tension developed in the muscle remains almost constant while the muscle changes its length.
    - **Concentric isotonic contraction:** generate force by changing the length of the muscle and can be concentric contractions or eccentric contractions. A concentric contraction causes muscles to shorten, thereby generating force
    - *An example of a concentric contraction in the raising of a weight during a bicep curl*
    - **Eccentric isotonic contraction:** is the motion of an active muscle while it is lengthening under load. Eccentric training is repetitively doing eccentric muscle contractions
    - *The simplest example of an eccentric contraction is lowering a barbell in a biceps curl*

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Isotonic and Isometric Contractions

- **Isometric contraction**
  - The tension generated is not enough to exceed the resistance of the object to be moved and the muscle does not change in length.
  - Is also known as **static strength training**. Examples include the plank and side bridge as well as the wall sit and many yoga poses such as chair and tree poses

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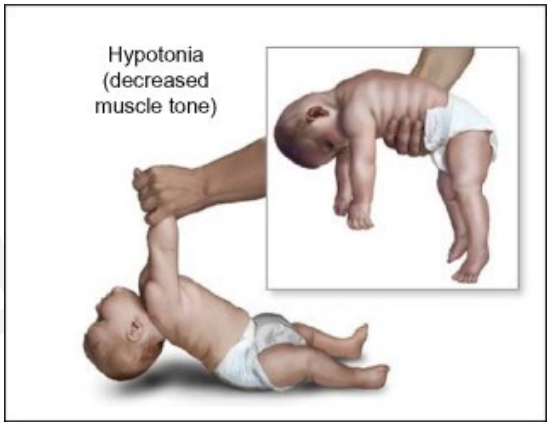
Clinical Connection

- **Hypotonia:**commonly known as floppy baby syndrome, is a state of low muscle tone (the amount of tension or resistance to stretch in a muscle), often involving reduced muscle strength
- **Hypertonia:** Increased tightness of muscle tone and reduced capacity of the muscle to stretch caused by damage to the motor nerve pathways in the central nervous system. Untreated hypertonia can lead to loss of function and deformity. Treatment can include physical and/or occupational therapy or medications



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Types of Skeletal Muscle Fibers

- Skeletal muscle fibers vary in their content of myoglobin (an O_2-binding protein).
  - **Red muscle fibers:**Red muscles are skeletal muscles that are rich in capillaries, myoglobin, and mitochondria. ... And good thing too, because they have a lot of slow-twitch fibers, which makes red muscles able to contract slowly but for an extended amount of time without tiring out (think: back muscles).
  - **White muscle fibers:** White muscles have fewer capillaries, myoglobin, and mitochondria. White muscles contain fast-twitch fibers, enabling them to contract real fast and with a lot of force, but they can't sustain the contraction for very long before tiring out

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Types of Skeletal Muscle Fibers

- There are three main classifications of skeletal muscle fiber:
  - **Slow oxidative (SO) fibers:** contract relatively slowly and use aerobic respiration (oxygen and glucose) to produce ATP. ... More ATP can be produced during each metabolic cycle, making the fiber more resistant to fatigue. Glycolytic fibers primarily create ATP through anaerobic glycolysis, which produces less ATP per cycle
  - **Fast oxidative-glycolytic (FOG) fibers:** Intermediate fibers, also known as fast oxidative-glycolytic fibers, are fast twitch muscle fibers which have been converted via endurance training. These fibers are slightly larger in diameter, have more mitochondria as well as a greater blood supply and more endurance than typical fast twitch fibers
  - **Fast glycolytic (FG) fibers:**have relatively fast contractions and primarily use anaerobic glycolysis. ... Fast fibers hydrolyze ATP approximately twice as rapidly as slow fibers, resulting in much quicker cross-bridge cycling (which pulls the thin filaments toward the center of the sarcomeres at a faster rate).

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Exercise and Skeletal Muscle Tissue

- The relative ratio of fast glycolytic (FG) and slow oxidative (SO) fibers in each muscle is genetically determined and helps account for individual differences in physical performance.

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Clinical Connection

- **Muscular dystrophy:** is a term that refers to a number of diseases that cause progressive loss of muscle mass resulting in weakness and, sometimes, loss of mobility.

- There are many different kinds of muscular dystrophy, each affecting different groups of muscles. In some types of muscular dystrophy, symptoms begin in childhood. In other forms, symptom onset doesn't occur until adulthood.

- Each of the different types of muscular dystrophy is caused by a mutation, or flaw, in a gene that interferes with the production of proteins needed to form and maintain healthy muscle. Such mutations may result in cells manufacturing a defective form of a particular protein, or insufficient (or completely absent) levels of that protein

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Aging and Muscular Tissue

- Between the ages of 30 and 50, an estimated 10% of muscle mass is lost.
- Another 40% is lost by age 80.

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Cardiac Muscle Tissue

- **Striated, involuntary, uninucleate, and branched**
- **Autorhythmicity:** the unique ability to initiate a cardiac action potential at a fixed rate – spreading the impulse rapidly from cell to cell to trigger the contraction of the entire heart. … The pacemaker cells make up just (1% of cells) and form the conduction system of the heart
- **Intercalated discs:** are unique structural formations found between the myocardial cells of the heart. They play vital roles in bonding cardiac muscle cells together and in transmitting signals between cells.
- **Desmosomes:**
- **Gap junctions:**

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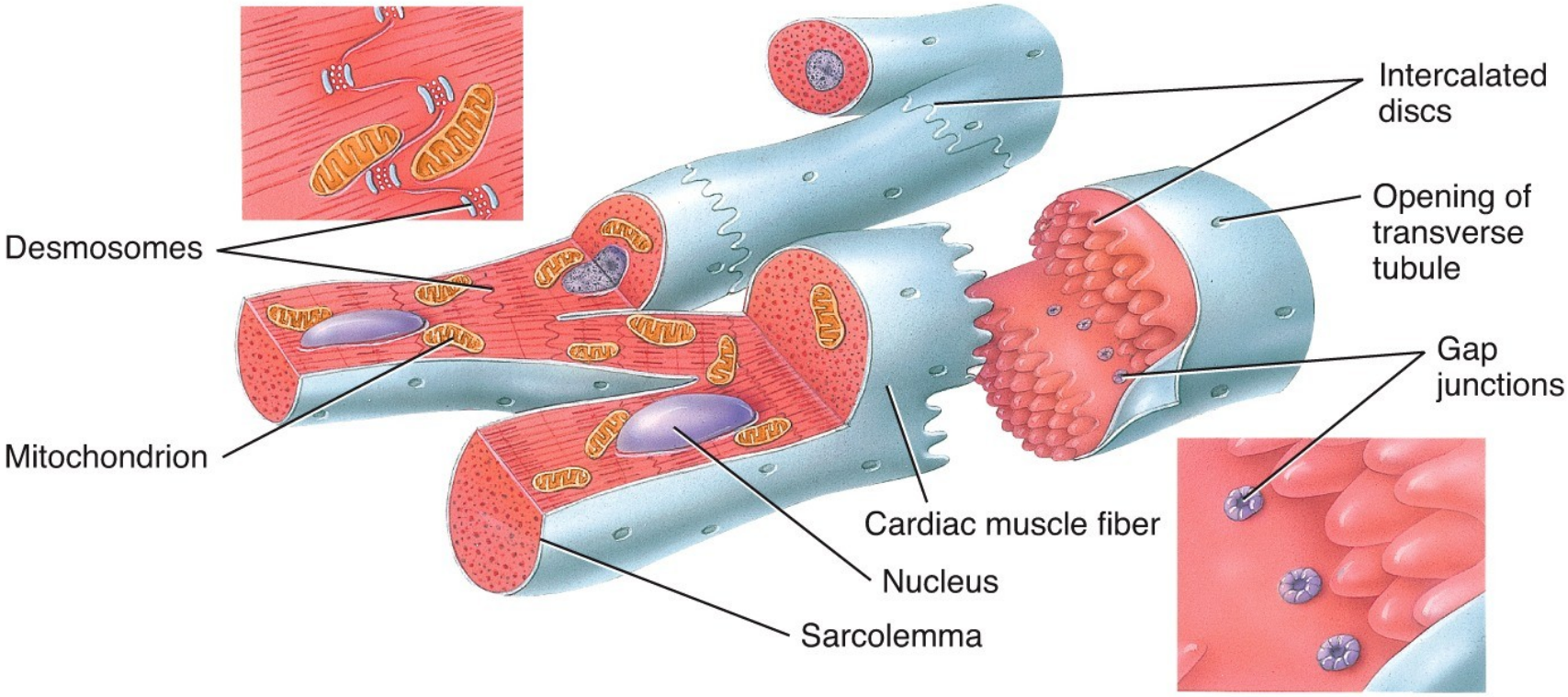
Histology of Cardiac Muscle



(a) Cardiac muscle fibers

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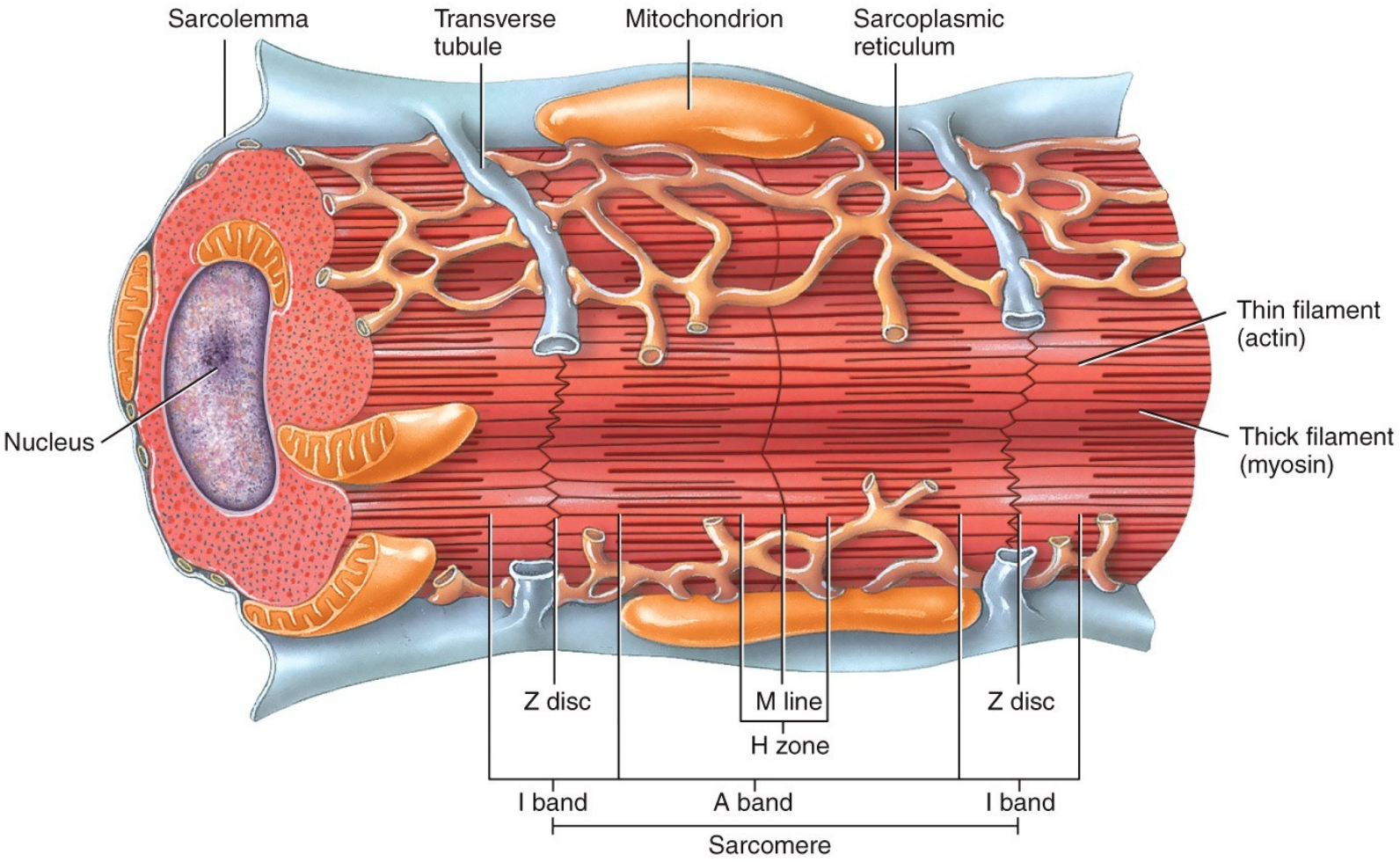
Histology of Cardiac Muscle



(b) Arrangement of components in a cardiac muscle fiber

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Smooth Muscle Tissue

- Involuntary, non-striated, uninucleate, and tapered cells
- There are two types of smooth muscle:
  - Visceral (single-unit) smooth muscle tissue
  - Multiunit smooth muscle tissue

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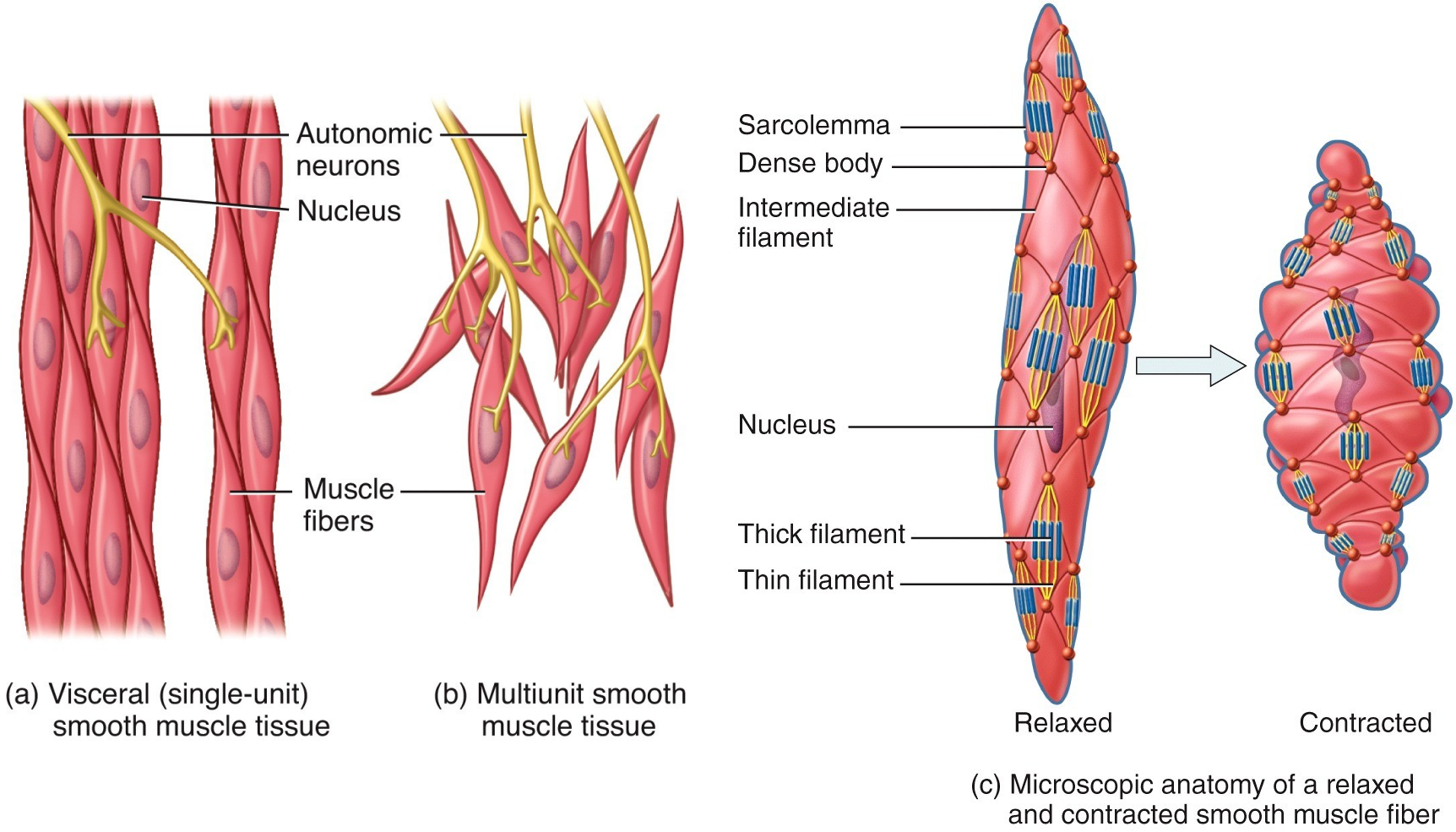
Histology of Smooth Muscle Tissue



(a) Visceral (single-unit) smooth muscle tissue

(b) Multiunit smooth muscle tissue

(c) Microscopic anatomy of a relaxed and contracted smooth muscle fiber

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Development of Muscles

- **Mesoderm:** is one of the three primary germ layers in the very early embryo. The other two layers are the ectoderm (outside layer) and endoderm (inside layer), with the mesoderm as the middle layer between them.
- Somitomeres: are derived from the loose masses of paraxial mesoderm

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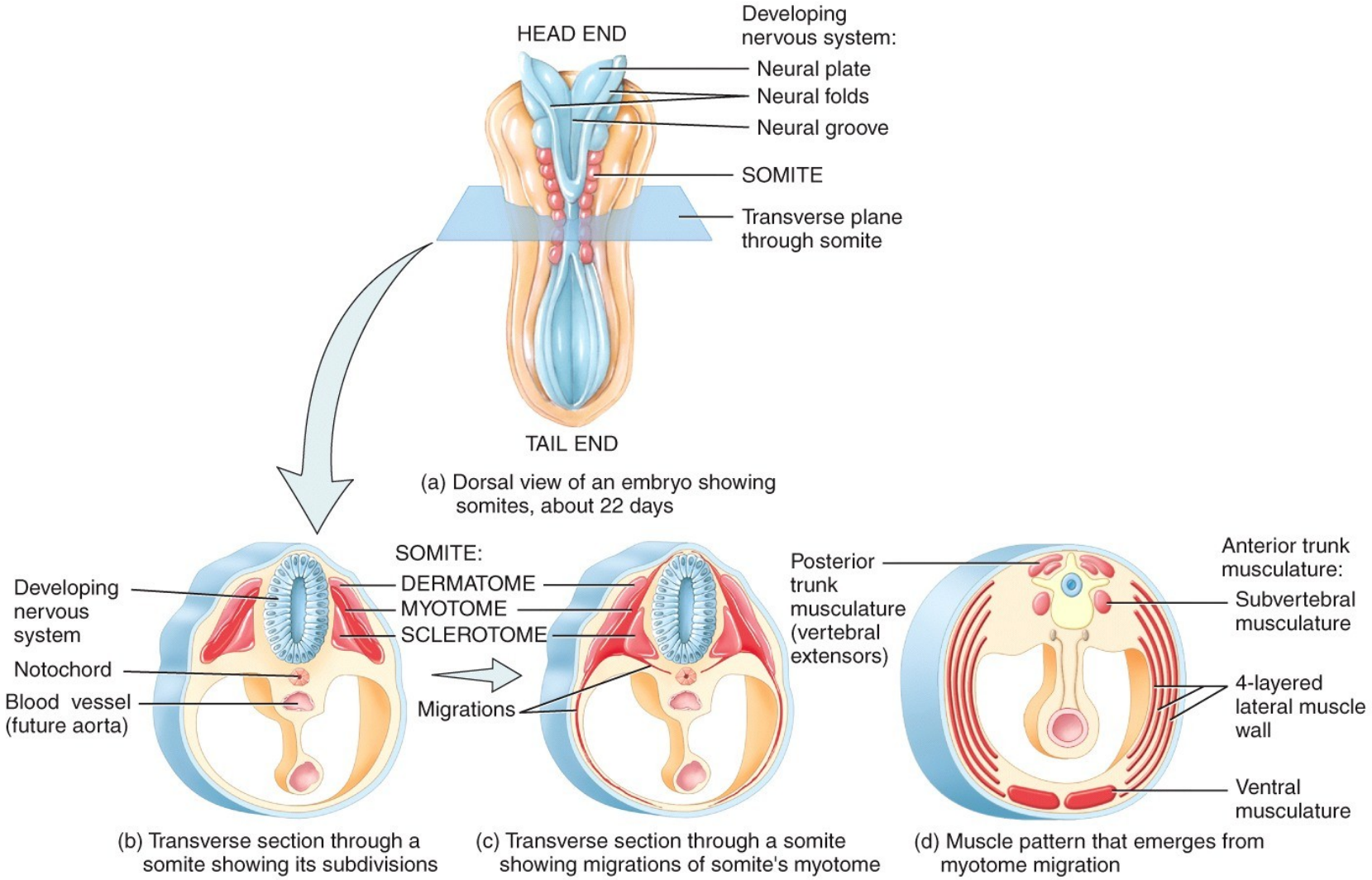
Location and Structure of Somites



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