PHYSIOLOGY

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LECTURE 7-PART (1)-LAST PART OF THE FIRST EXAM
ULTRASTRUCTURE OF MUSCLE CELLS AND MOLECULAR MECHANISM OF CONTRACTION

Objectives

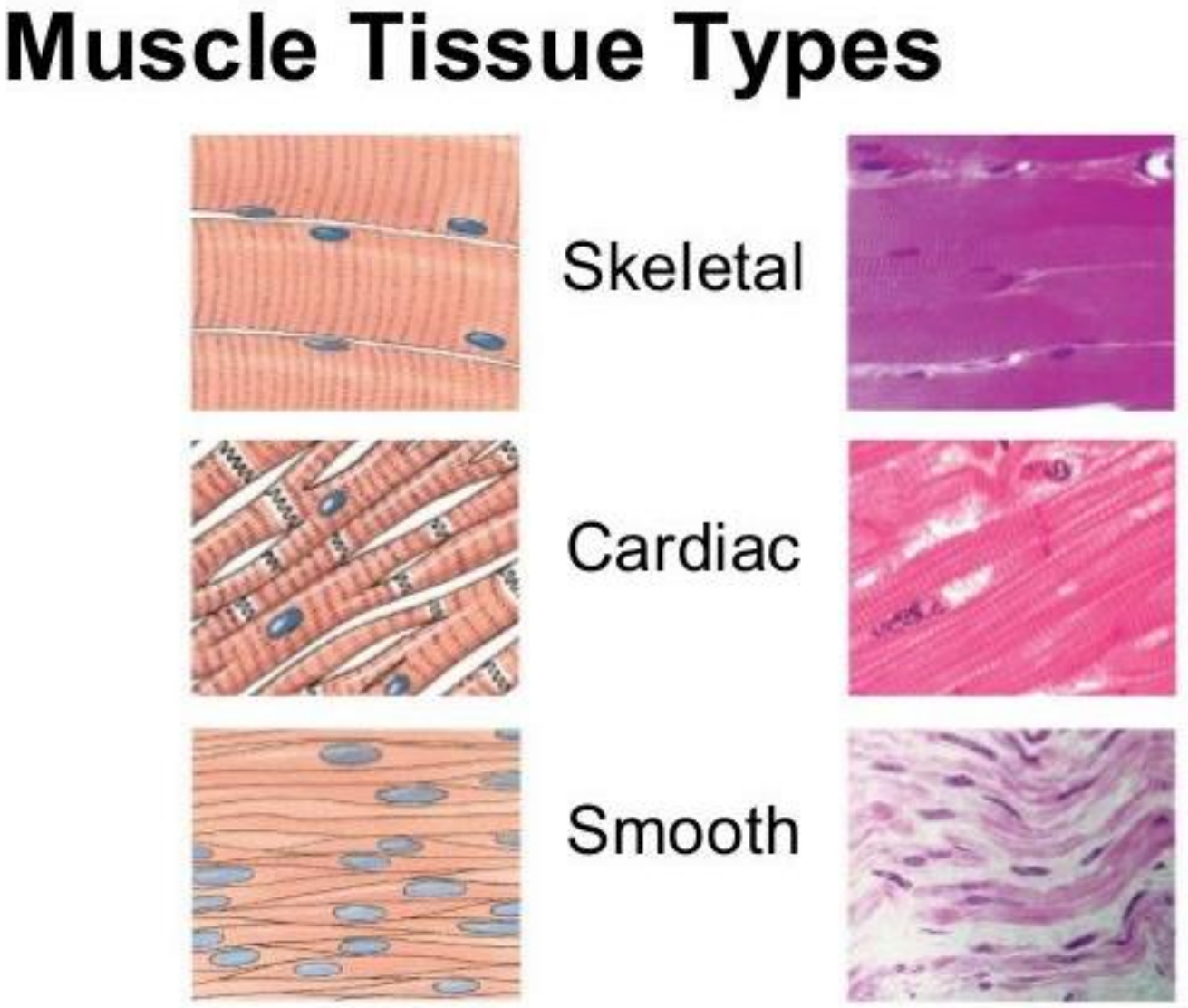
1. Discuss **ultrastructure of muscle cells.**

2. Describe **molecular mechanism of contraction.**

(Pages 292-308 of the reference)

General Overview

The three types of muscular tissue are skeletal, cardiac, and smooth.



SKELETAL MUSCLE TISSUE

- **Skeletal muscle tissue** is so named because most skeletal muscles move the bones of the skeleton. **Alternating light and dark protein bands** (striations) are seen when the tissue is examined with a microscope.

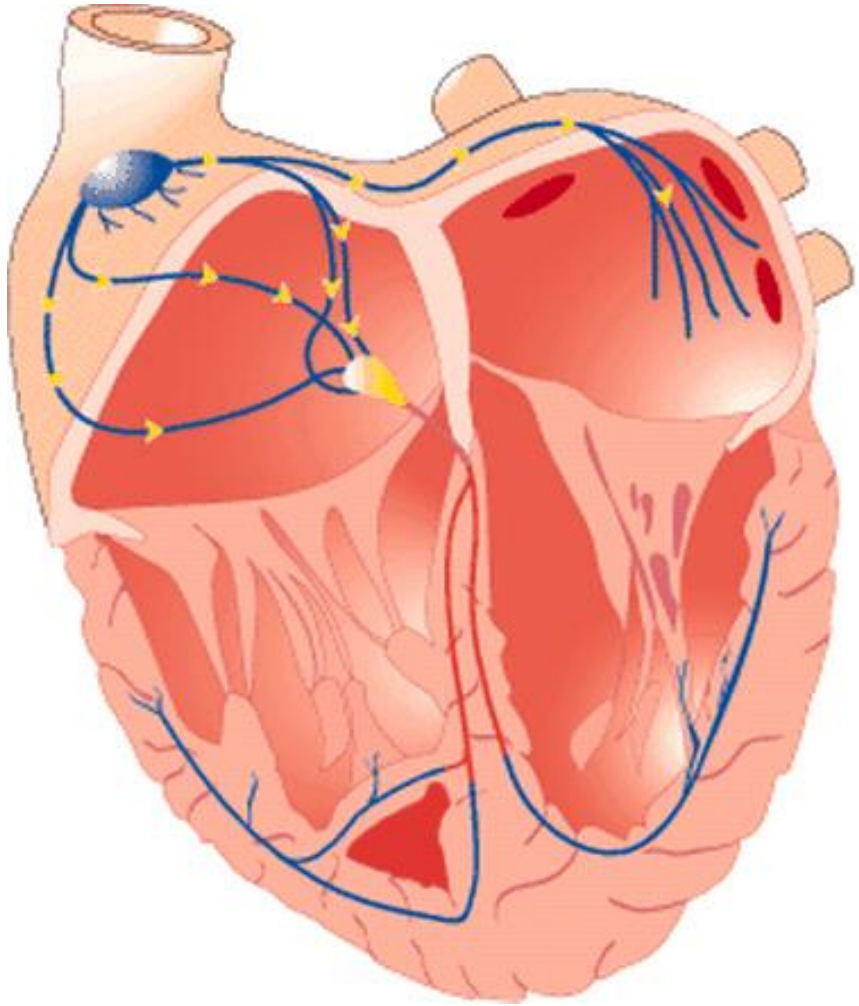
- Skeletal muscle tissue works **mainly in a voluntary manner**. Its activity can be **consciously** controlled by neurons (nerve cells) that are part of the somatic (voluntary) division of the nervous system.

- Most skeletal muscles also are **controlled subconsciously** to some extent. For example, your diaphragm continues to alternately contract and relax without conscious control so that you don't stop breathing. Also, you do not need to consciously think about contracting the skeletal muscles that maintain your posture or stabilize body positions.

CARDIAC MUSCLE TISSUE

- The alternating contraction and relaxation of the **heart is not consciously controlled**. Rather, the heart beats because it has a natural pacemaker that initiates each contraction.

- This built-in rhythm is termed **autorhythmicity**. Several hormones and neurotransmitters can adjust heart rate by speeding or slowing the pacemaker.



SMOOTH MUSCLE TISSUE

It is located in the walls of hollow internal structures, such as blood vessels, airways, and most organs in the abdominopelvic cavity.

The action of smooth muscle is usually involuntary, and some smooth muscle tissue, such as the muscles that propel food through your gastrointestinal tract, has autorhythmicity.

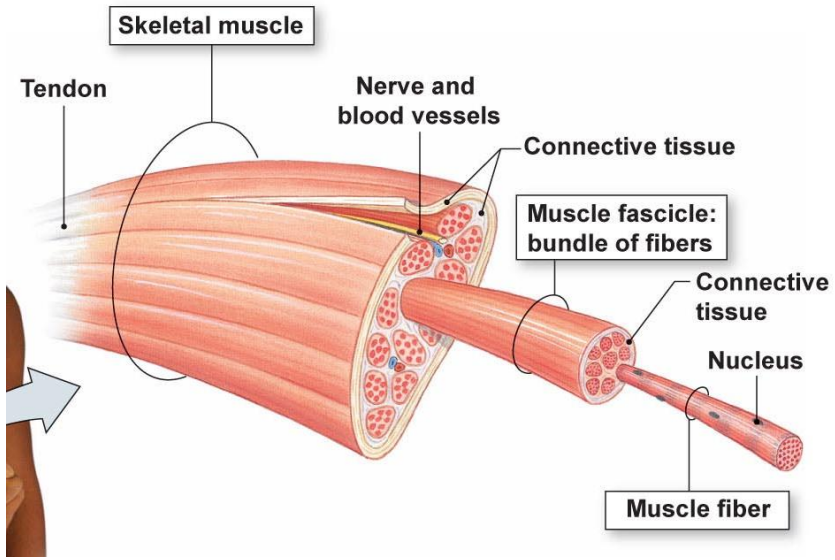
FUNCTIONS OF MUSCULAR TISSUE

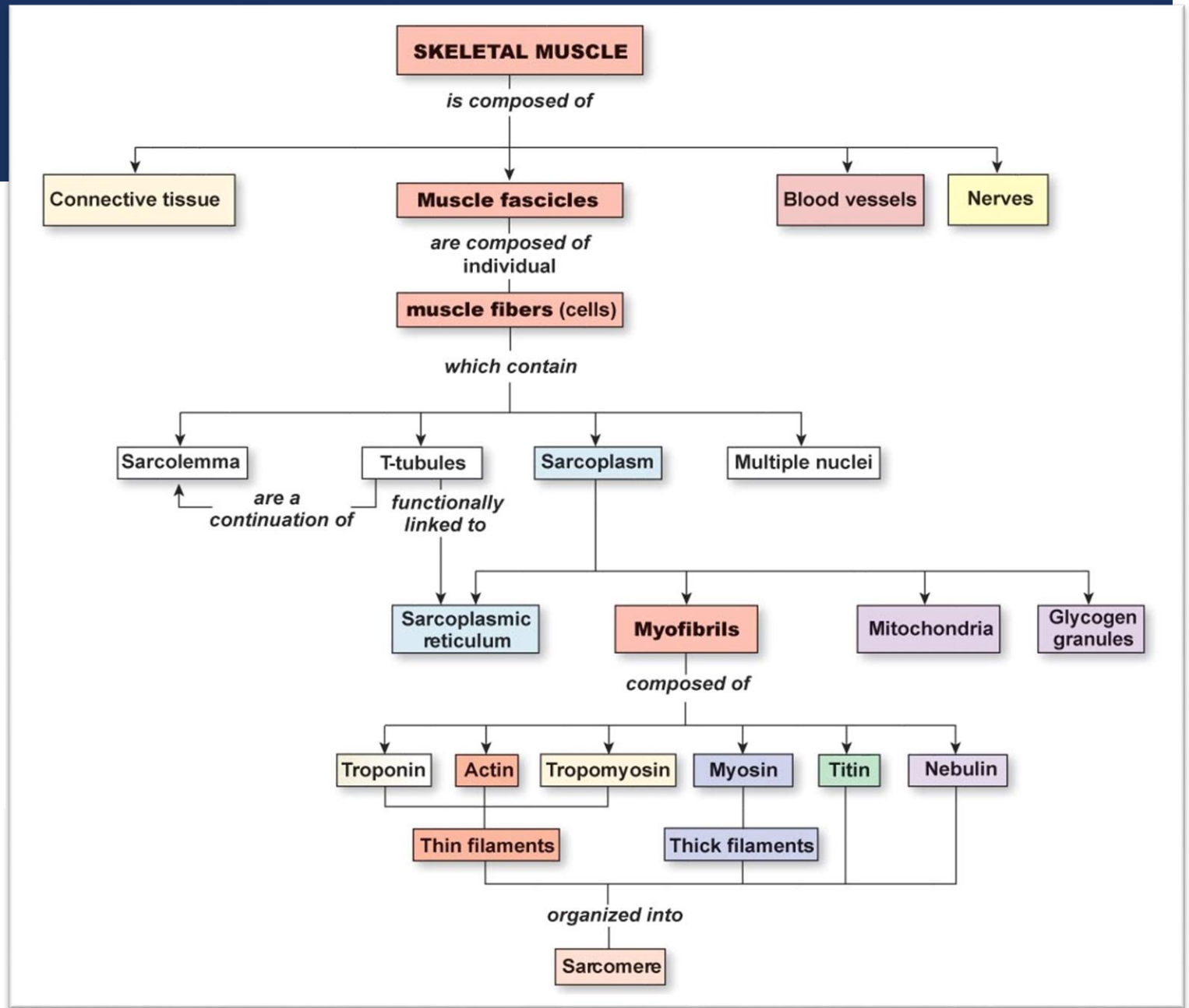
1. **Producing body movements** (movements of the whole body, and localized movements).
2. **Stabilizing body positions** (such as standing or sitting, neck muscles hold your head upright).
3. **Storing and moving substances within the body** (storage is accomplished by sustained contractions of ringlike bands of smooth muscle called sphincters (i.e., gastrointestinal tract). Contraction and relaxation of smooth muscle in the walls of blood vessels help adjust blood vessel diameter and thus regulate the rate of blood flow.
4. **Generating heat** (As muscular tissue contracts, it produces heat, a process known as thermogenesis (maintaining normal body temperature)).

PROPERTIES OF MUSCULAR TISSUE

1. **Electrical excitability** respond to certain stimuli by producing electrical signals called **action potentials (impulses)** (i.e., autorhythmic electrical signals arising in the muscular tissue itself, as in the heart's pacemaker or chemical stimuli, such as neurotransmitters released by neurons, hormones distributed by the blood, or even local changes in pH).
2. **Contractility** (ability of muscular tissue to contract forcefully when stimulated by an action potential).
3. **Extensibility** (ability of muscular tissue to stretch, within limits, without being damaged (i.e., smooth muscle in the stomach and cardiac muscle)).
4. **Elasticity** (ability of muscular tissue to return to its original length and shape after contraction or extension).

SKELETAL MUSCLE
FUNCTIONAL ANATOMY





CONNECTIVE TISSUE COMPONENTS

1. **Subcutaneous layer or hypodermis** (which separates muscle from skin, is a pathway for nerves, blood vessels, and lymphatic vessels to enter and exit muscles).

2. **Adipose tissue of the subcutaneous layer** (stores most of the body's triglycerides, serves as an insulating layer that reduces heat loss, and protects muscles from physical trauma).

3. **Fascia** (is a dense sheet or broad band of irregular connective tissue that lines the body wall and limbs and supports and surrounds muscles and other organs of the body.).

NERVE AND BLOOD SUPPLY

- **Skeletal muscles are well supplied with nerves and blood vessels**.
- Generally, an artery and one or two veins accompany each nerve that penetrates a skeletal muscle.
- The neurons that **stimulate skeletal muscle to contract are somatic motor neurons**. Each somatic motor neuron has a threadlike axon that extends from the brain or spinal cord to a group of skeletal muscle fibers.
- The axon of a somatic motor neuron typically branches many times, each branch extending to a different skeletal muscle fiber.
- The blood capillaries bring in oxygen and nutrients and remove heat and the waste products of muscle metabolism.

MICROSCOPIC ANATOMY OF A SKELETAL MUSCLE FIBER

- Because each skeletal muscle fiber **arises during embryonic development from the fusion** of a hundred or more small mesodermal cells called **myoblasts**, each mature skeletal muscle fiber has a hundred or more nuclei.

- Once fusion has occurred, **the muscle fiber loses its ability to undergo cell division**. Thus, **the number of skeletal muscle fibers is set** before you are born, and most of these cells last a lifetime.

MICROSCOPIC ANATOMY OF A SKELETAL MUSCLE FIBER

- **Sarcolemma** is the plasma membrane of a muscle cell.
- **Transverse (T) tubules** which are tunnels in from the surface toward the center of each muscle fiber.
- Muscle action potentials travel along the sarcolemma and through the T tubules, quickly spreading throughout the muscle fiber.
- **Sarcoplasm** is the cytoplasm of a muscle fiber which includes a substantial amount of **glycogen**, which is a large molecule composed of many glucose molecules. In addition, the sarcoplasm contains a red-colored protein called **myoglobin.** It binds oxygen molecules that diffuse into muscle fibers and releases oxygen when it is needed by the mitochondria for ATP production.

MICROSCOPIC ANATOMY OF A SKELETAL MUSCLE FIBER

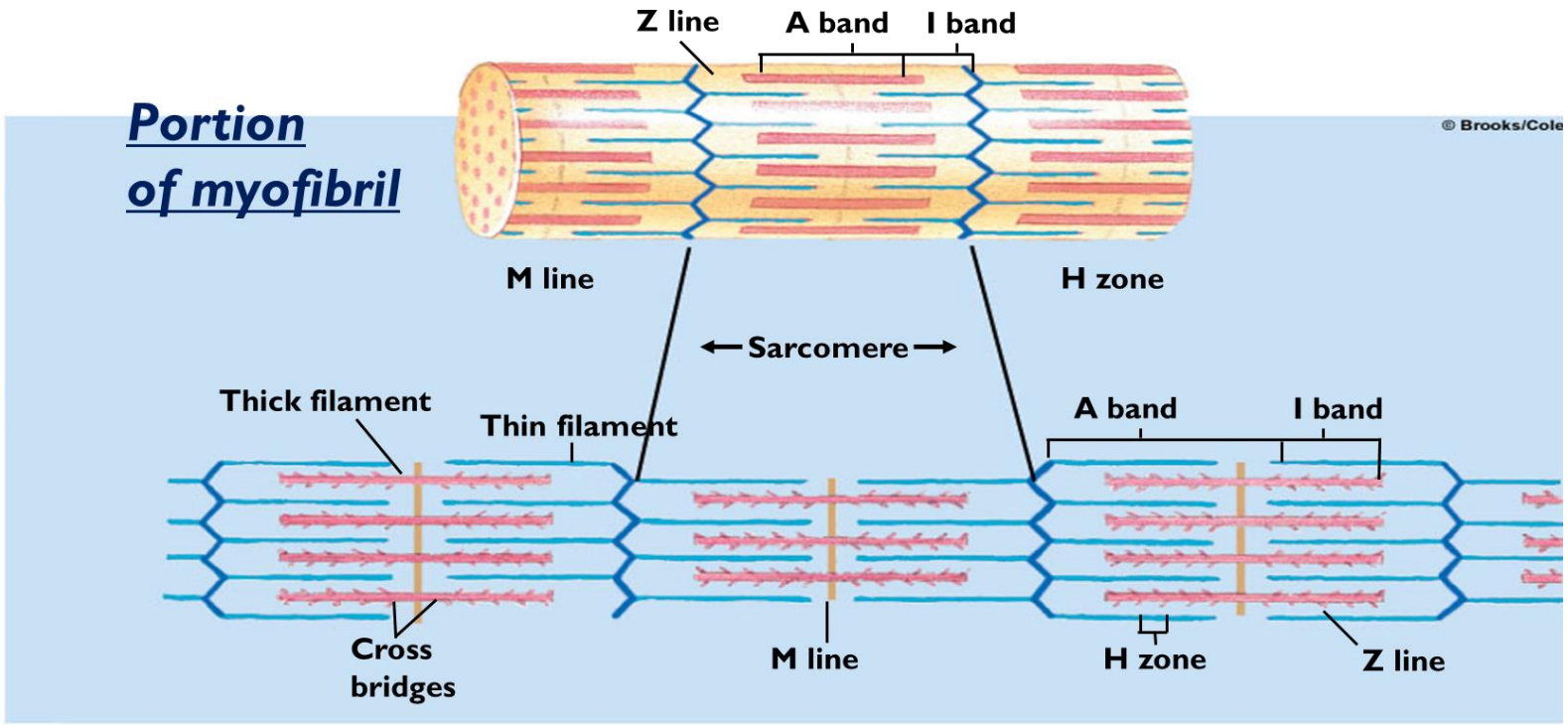
- **Myofibrils,** the contractile organelles of skeletal muscle.
- Fluid-filled system of membranous sacs **called the sarcoplasmic reticulum (SR)** encircles each myofibril**.**
- In a relaxed muscle fiber, the sarcoplasmic reticulum stores calcium ions. Release of calcium ions from the sarcoplasmic reticulum triggers muscle contraction.

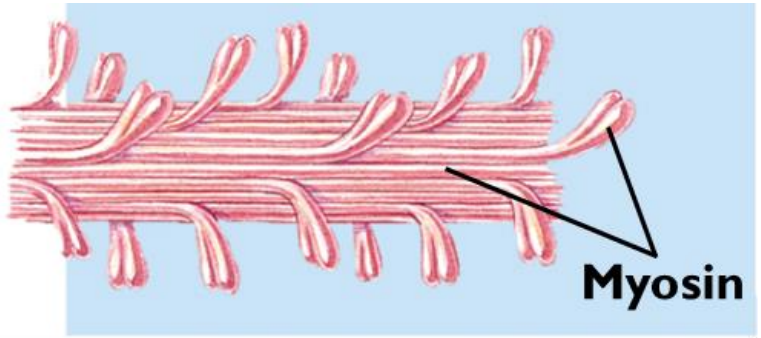
MICROSCOPIC ANATOMY OF A SKELETAL MUSCLE FIBER

- Within myofibrils are smaller protein structures called **filaments or myofilaments**. They are arranged in compartments called **sarcomeres**. The plate-shaped regions of dense protein material called **Z discs** separate one sarcomere from the next. Thus, a sarcomere extends from one Z disc to the next Z disc

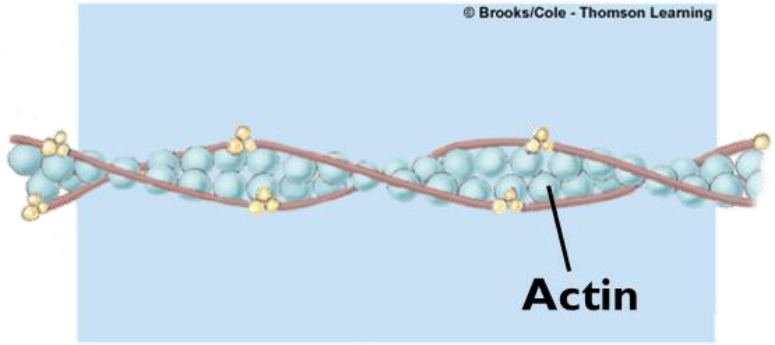
- **Thin filaments** are 8 nm in diameter and 1–2 μm long and composed mostly of the protein actin, while **thick filaments** are 16 nm in diameter and 1–2 μm long and composed mostly of the protein myosin.

- **The myofibrils** are organized into a repetitive pattern, the sarcomere.
- **Myosin**: thick filament.
- **Actin**: thin filament.
- Bands formed by pattern: **A and I and H bands.**
- **Z line**: area of attachment of the actin fibers.
- **M line**: Myosin fiber centers.





Thick filament



Thin filament

MUSCLE PROTEINS

1-**Contractile proteins** generate force during muscle contractions.

2-**Regulatory proteins** help switch the contraction process on and off.

3-**Structural proteins** keep the thick and thin filaments in the proper alignment, give the myofibril elasticity and extensibility.

CONTRACTILE PROTEINS

- **Myosin** is the motor protein in all three types of muscle tissue and makes up thick filament, which consists of a tail and two myosin heads .

- **Motor proteins** pull various cellular structures to achieve movement (muscle contractions) by **converting the chemical energy in ATP to the mechanical energy of motion**, that is, the **production of force**.

- Thin filaments are anchored to Z discs. Their main component is the protein **actin**. On each actin molecule is a myosin-binding site, where a myosin head can attach during muscle contraction.

REGULATORY PROTEINS

- They are **tropomyosin** and **troponin,** that help switch muscle contraction process on and off.

- In **relaxed muscle**, myosin is blocked from binding to actin because **strands of tropomyosin cover the myosin binding sites on actin**. The tropomyosin strands in turn are held in place by troponin molecules.

- When **calcium ions bind to troponin**, it undergoes a change in shape; this change moves tropomyosin away from myosin-binding sites on actin and **muscle contraction subsequently begins as myosin binds to actin**.

STRUCTURAL PROTEINS

- They contribute to the alignment, stability, elasticity, and extensibility of myofibrils.
- Several key structural proteins are **titin, α-actinin, myomesin, nebulin, and dystrophin**.
- **Titin** is the third most plentiful protein in skeletal muscle (after actin and myosin), it has a huge size. It accounts for much of the elasticity and extensibility of myofibrils.
- **Titin** probably helps the muscle return to its resting length after a muscle has contracted or been stretched ,and it may help prevent overextension of muscles; thereby helping to stabilize thick filament position.

CONTRACTION AND RELAXATION OF SKELETAL MUSCLE FIBERS

- *Scientists were surprised to see that the lengths of the thick and thin filaments were the same in both relaxed and contracted muscle. It had been thought that muscle contraction must be a folding process, somewhat like closing an accordion. Instead, researchers discovered that skeletal muscle shortens during contraction because the thick and thin filaments slide past one another. The model describing this process is known as* ***the sliding filament mechanism.***

THE SLIDING FILAMENT MECHANISM

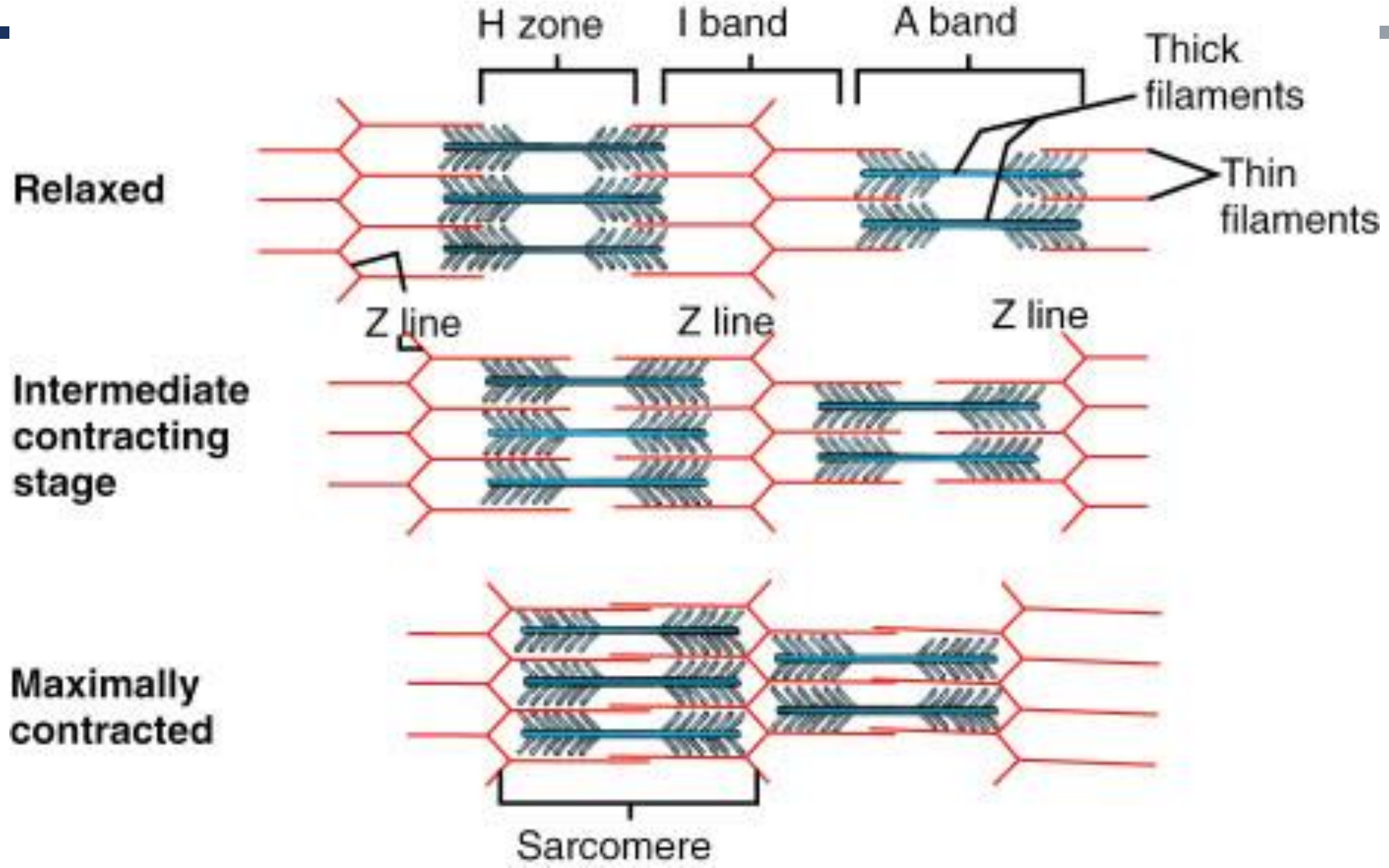
- **Muscle contraction** occurs because myosin heads attach to and "walk" along the thin filaments at both ends of a sarcomere, followed by:

1- Progressively pulling the thin filaments toward the **M line**.
2- As the thin filaments slide inward, the **I band** and **H zone** narrow and eventually disappear altogether when the muscle is maximally contracted. However, the width of the **A band** and the individual lengths of the thick and thin filaments remain unchanged.

THE SLIDING FILAMENT MECHANISM

3-Since the thin filaments on each side of the sarcomere are attached to Z discs, when the thin filaments slide inward, the Z discs come closer together, and the sarcomere shortens.

4- Shortening of the sarcomeres causes shortening of the whole muscle fiber, which in turn leads to shortening of the entire muscle.


H zone
I band
A band
Thick filaments
Thin filaments
Relaxed
Z line
Z line
Z line
Intermediate contracting stage
Maximally contracted
Sarcomere

THE CONTRACTION CYCLE

Contraction cycle consists of four steps:

1. ATP hydrolysis.
2. Attachment of myosin to actin to form cross-bridges.
3. Power stroke.
4. Detachment of myosin from actin.

ATP HYDROLYSIS

- The **myosin head** includes an **ATP-binding site** and an **ATPase**, an enzyme that hydrolyzes ATP into ADP (adenosine diphosphate) and a phosphate group.
- Notice that the products of ATP hydrolysis—ADP and a phosphate group—are still attached to the myosin head.

ATTACHMENT OF MYOSIN TO ACTIN TO FORM CROSS-BRIDGES

The energized myosin head attaches to the myosin-binding site on actin and releases the previously hydrolyzed phosphate group.

POWER STROKE

During the power stroke, the site on the cross-bridge where ADP is still bound opens. As a result, the cross-bridge rotates and releases the ADP. The cross-bridge generates force as it rotates toward the center of the sarcomere, sliding the thin filament past the thick filament toward the M line.

DETACHMENT OF MYOSIN FROM ACTIN

At the end of the power stroke, the cross-bridge remains firmly attached to actin until it binds another molecule of ATP. As ATP binds to the ATP binding site on the myosin head, the myosin head detaches from actin.

THE CONTRACTION CYCLE

Each of the 600 cross-bridges in one thick filament attaches and detaches about five times per second.

Figure 10.6 The Contraction Cycle

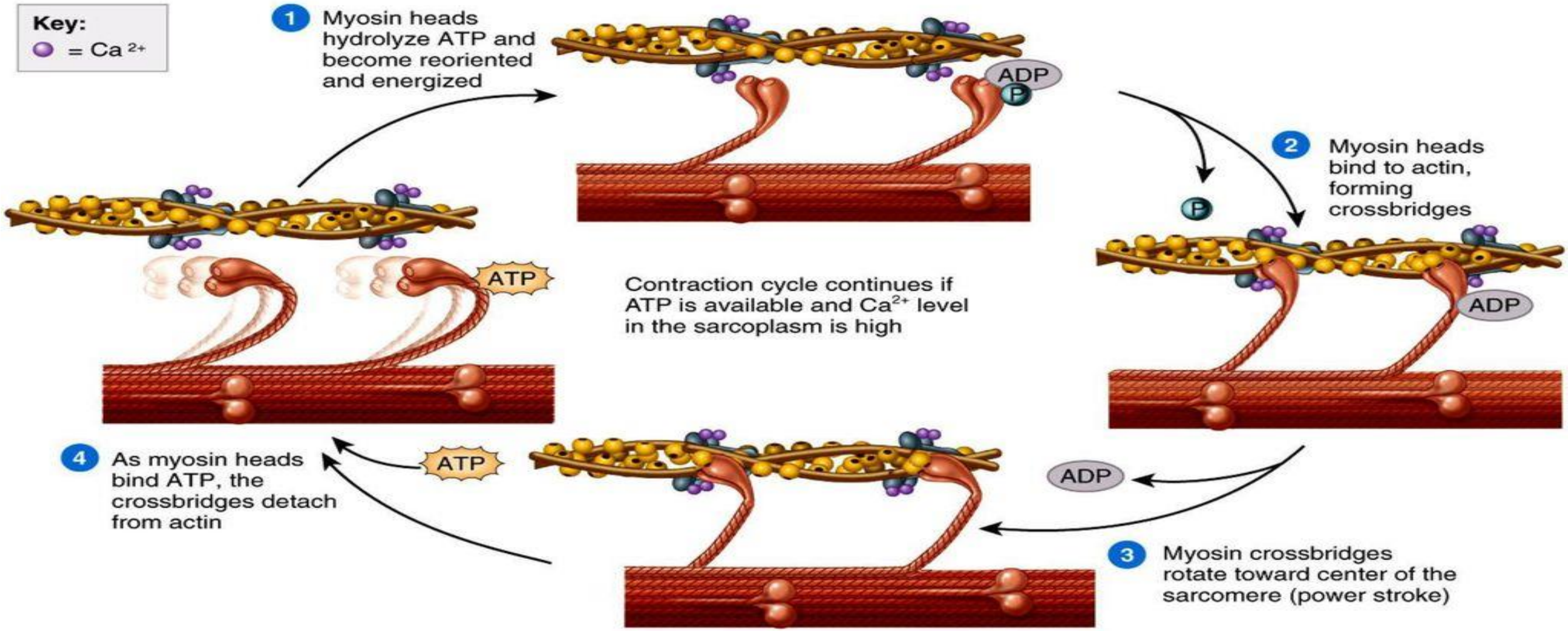
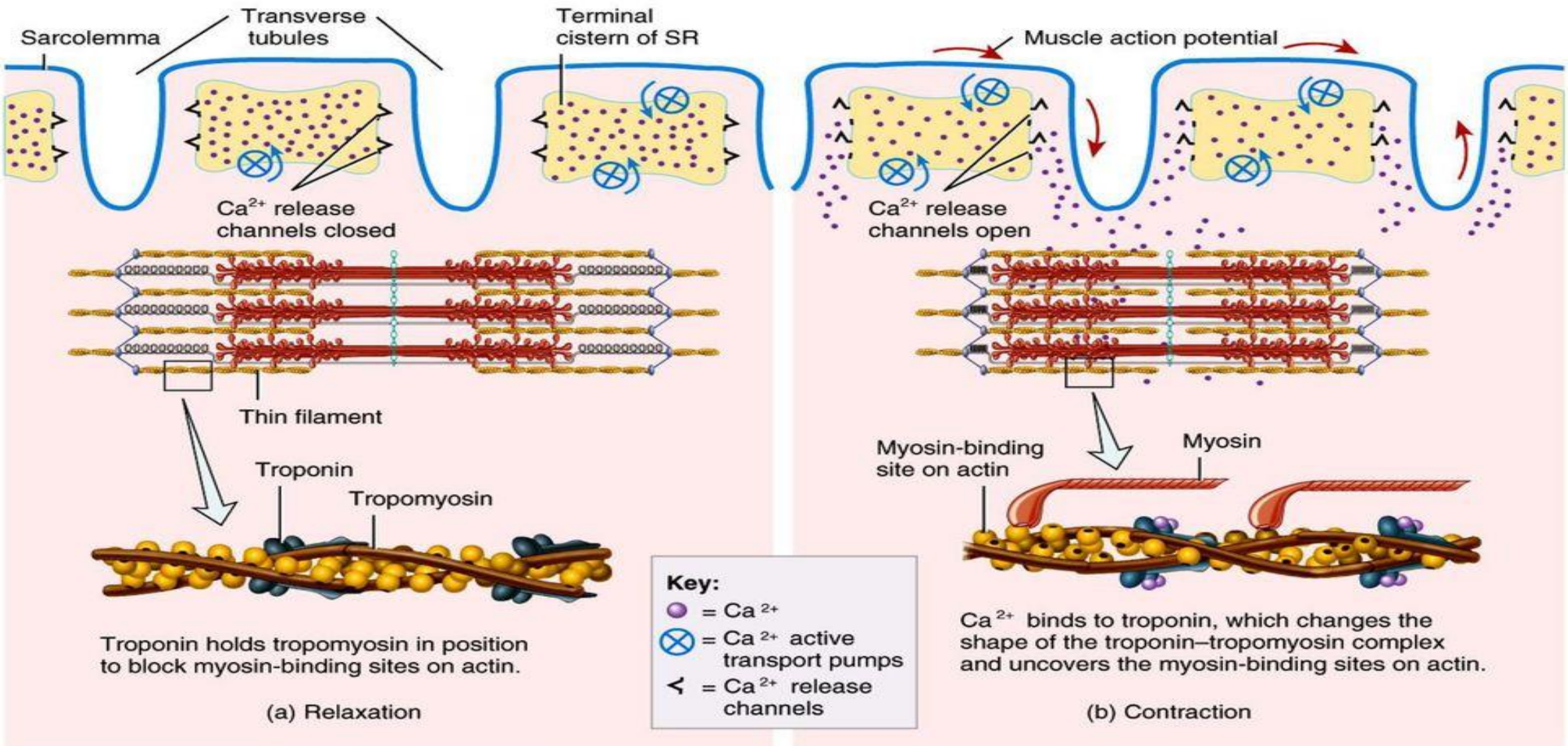


Figure 10.07 Tortora - PAP 12/e

EXCITATION–CONTRACTION COUPLING

The events just described are referred to collectively as **excitation–contraction coupling**, as they are the steps that connect **excitation** (a muscle action potential propagating along the sarcolemma and into the T tubules) to **contraction** (sliding of the filaments).

Figure 10.7 Excitation – Contraction Coupling



❖ **Synapse:** A functional connection between a neuron and another cell.

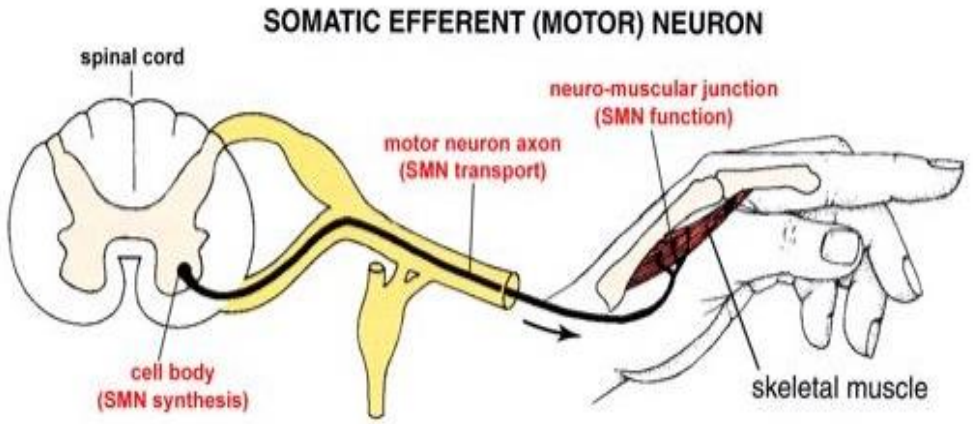
❖**Two types of synapses:**

1. Electrical synapse.
2. Chemical synapse, i.e., neuromuscular junction.

Neuromuscular junction

NEUROMUSCULAR JUNCTION

- Is the junction (synapse) between a nerve (motor neuron) and a muscle cell (muscle fiber).



- Motor neuron is the neuron that innervates a muscle fiber.

- Motor unit : single motor neuron and the muscle fibers it innervate.

- As axon approaches muscle , it divides into many terminal branches and loses its myelin sheath.

- Each of these axon terminal forms special junction, a **neuromuscular junction** with one of the many cells that form the whole muscle.

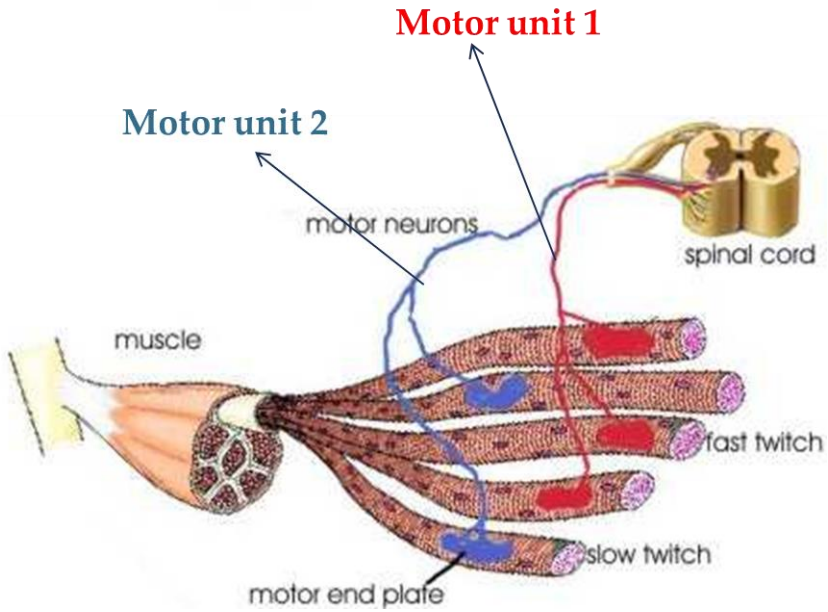
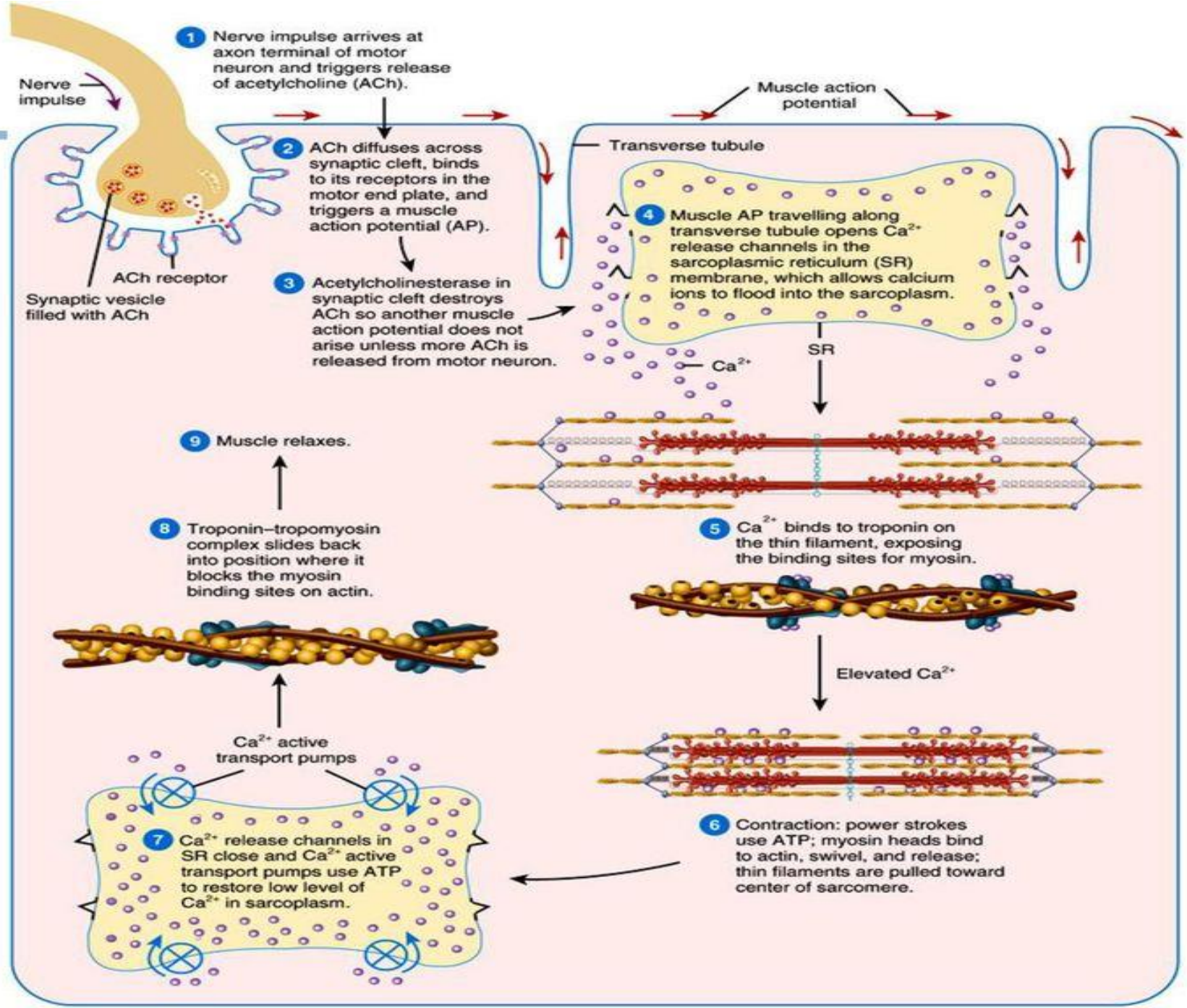


Figure 10.10

Summary of the Events of Contraction and Relaxation in a Skeletal Muscle Fiber



THANK YOU

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