Course: Animal form and function

AN INTRODUCTION TO ANIMAL MUSCLES

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Muscular tissue is the driving force, the power behind movement in most invertebrates and vertebrates.

Properties of muscle tissue:

- **Contractility**

  the ability to contract or shorten

- **excitability (or irritability)**

  the capacity to receive and respond to a stimulus

- **extensibility**

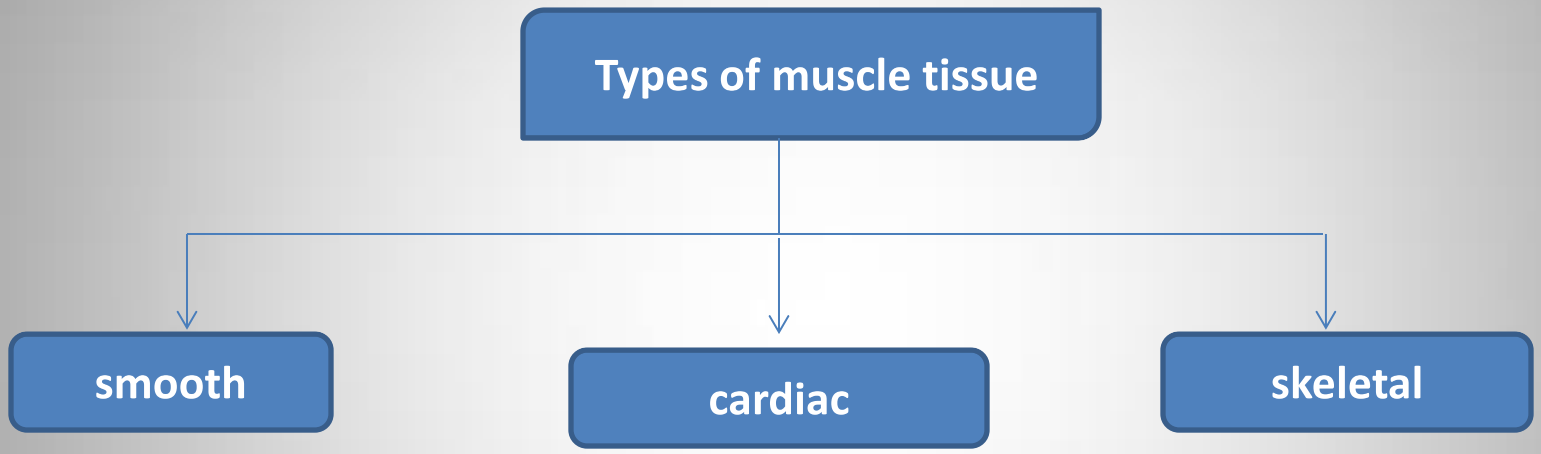
  the ability to be stretched

- **Elasticity**

  the ability to return to its original shape after being stretched or contracted

Muscle tissue

Animals may have one or more of the following types of muscle tissue. The contractile cells of these tissues are called **muscle fibers**.

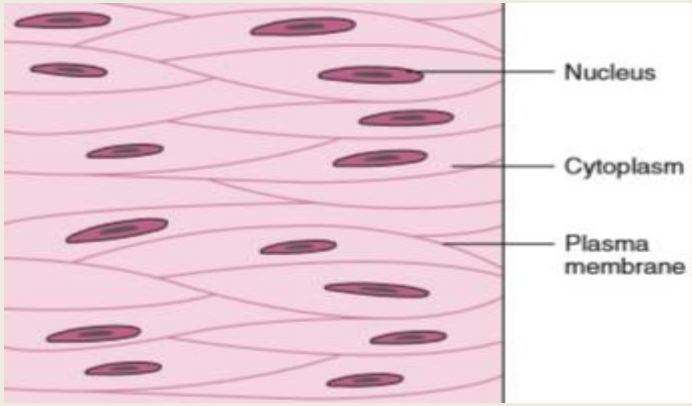


1) Smooth muscle:

- ✓ Involuntary muscle
- ✓ Smooth muscle fibers have a single nucleus, are spindle shaped, and are arranged in a parallel pattern.
- ✓ maintains good tone even without nervous stimulation
- ✓ contracts slowly
- ✓ sustain prolonged contractions
- ✓ does not fatigue (tire) easily.

Examples:

- ○ **adductor (“catch’’) muscles** that close the valves of clams and other bivalve molluscs.



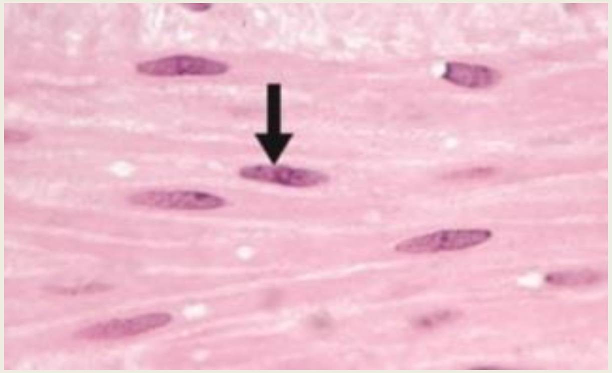


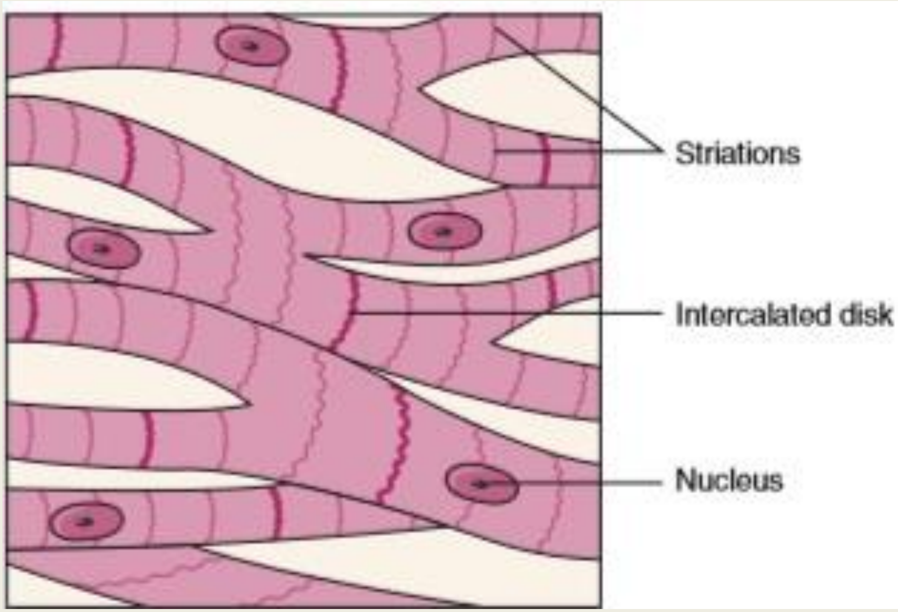
Fig: Smooth muscle tissue is formed of spindle-shaped cells, each containing a single nucleus (arrow). Cells are arranged closely to form sheets. Smooth muscle tissue is not striated. Location: Mostly in the walls of hollow organs. Function: Moves substances or objects (foodstuffs, urine, a baby) along internal passageways; involuntary control.

2) Cardiac muscle:

Striated muscle fibers (cells) with single nuclei are common in invertebrates, but they occur in adult vertebrates only in the heart, where they are called **cardiac muscle**.

Characteristics of Cardiac muscle fibers

- ✓ involuntary
- ✓ have a single nucleus
- ✓ striated
- ✓ branched
- ✓ Interlock for greater strength during contraction
- ✓ do not fatigue
- ✓ cardiac fibers relax completely between contractions.



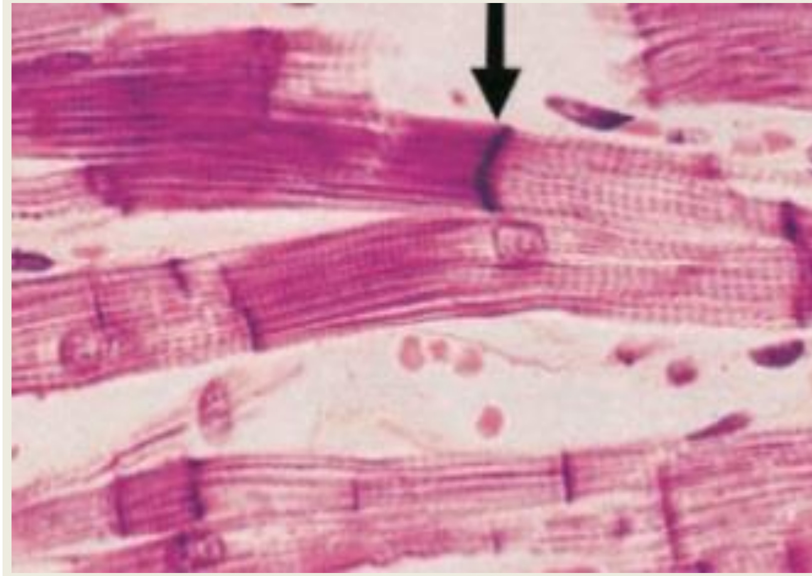


Fig: Cardiac muscle tissue consists of striated cells, each containing a single nucleus and specialized cell junctions called intercalated disks (arrow) that allow ions (action potentials) to move quickly from cell to cell. Location: The walls of the heart. Function: As the walls of the heart contract, cardiac muscle tissue propels blood into the circulation; involuntary control.

3) Skeletal muscle

Skeletal muscle, also a striated muscle, is a voluntary muscle because the nervous system consciously controls its contractions.

Characteristics of Cardiac muscle fibers

- ✓ striated
- ✓ multinucleated
- ✓ Skeletal muscles attach to skeletons (both endoand exoskeletons)
- ✓ When skeletal muscles contract, they shorten
- ✓ muscles can only pull; they cannot push
- ✓ work in antagonistic pairs

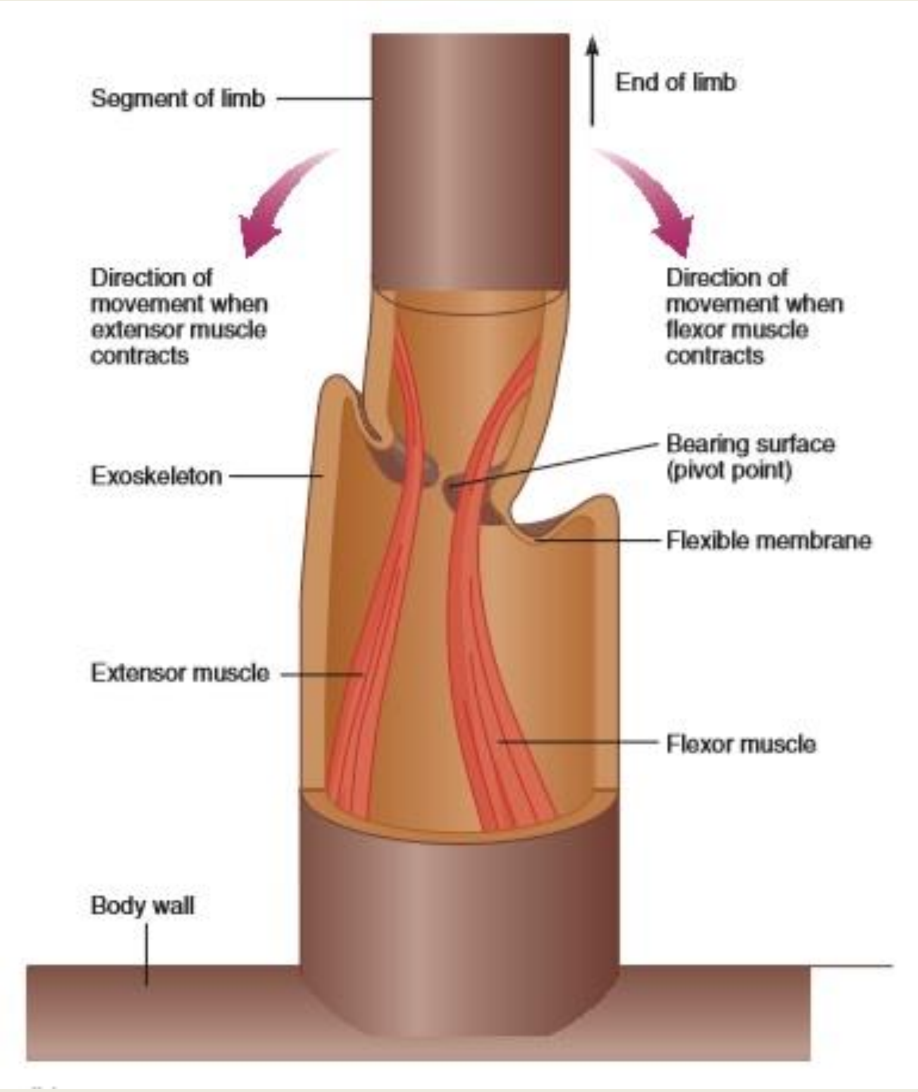
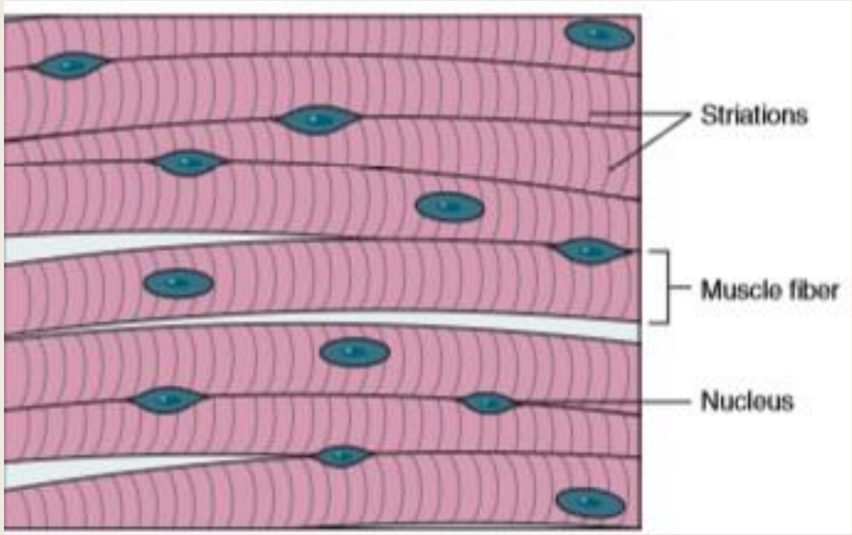


Fig: In an arthropod, muscles attach to the interior of the exoskeleton. In this articulation of an arthropod limb, the cuticle is hardened everywhere except at the joint, where the membrane is flexible. Notice that the extensor muscle is antagonistic to (works in an opposite direction than) the flexor muscle.



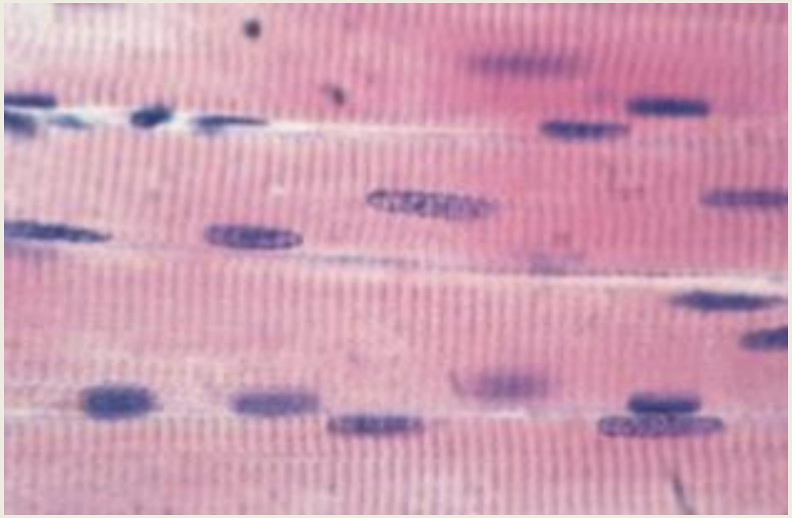


Fig: Skeletal muscle tissue is composed of striated muscle fibers (cells) that are long and cylindrical, and contain many peripheral nuclei. Location: In skeletal muscles attached to bones. Function: Voluntary movement, locomotion.

THE MUSCULAR SYSTEM OF INVERTEBRATES

1) The Locomotion of Soft-Bodied Invertebrates

pedal locomotion

example, flatworms, some cnidarians, and the gastropod molluscs

looping movements

example, Leeches and some insect larvae , Lepidopteran caterpillars

(parapodia)

example Polychaete worms

water-vascular system

example **echinoderms**

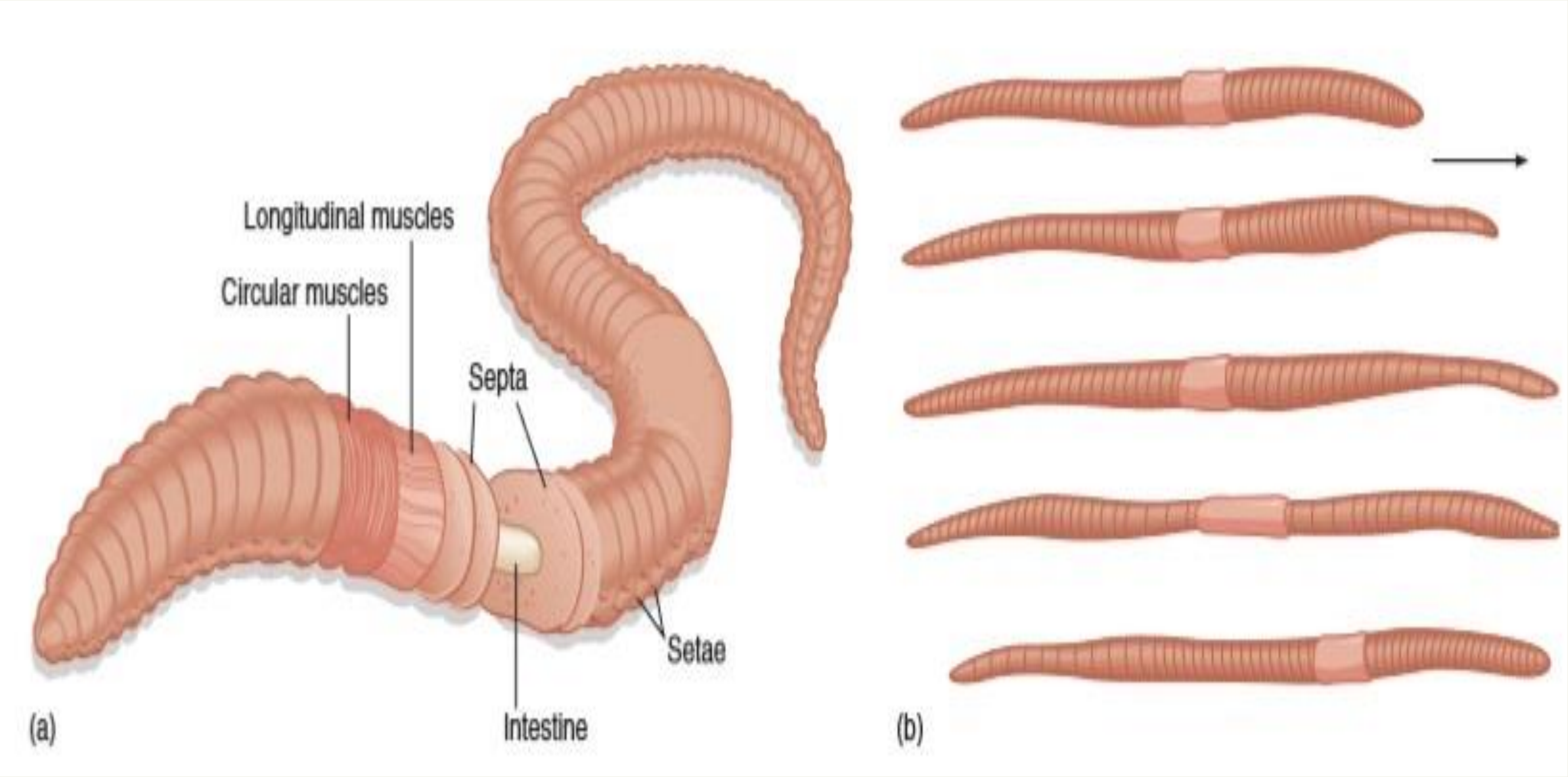


Fig: Successive Stages in Earthworm Movement. (a) When the longitudinal muscles contract and the circular muscles relax, the segments of the earthworm bulge and are stationary with respect to the ground. (b) In front of each region of longitudinal muscle contraction, circular muscles contract, causing the segments to elongate and push forward. Contraction of longitudinal muscles in segments behind a bulging region cause those segments to be pulled forward. For reasons of simplification, setae movements are not shown.

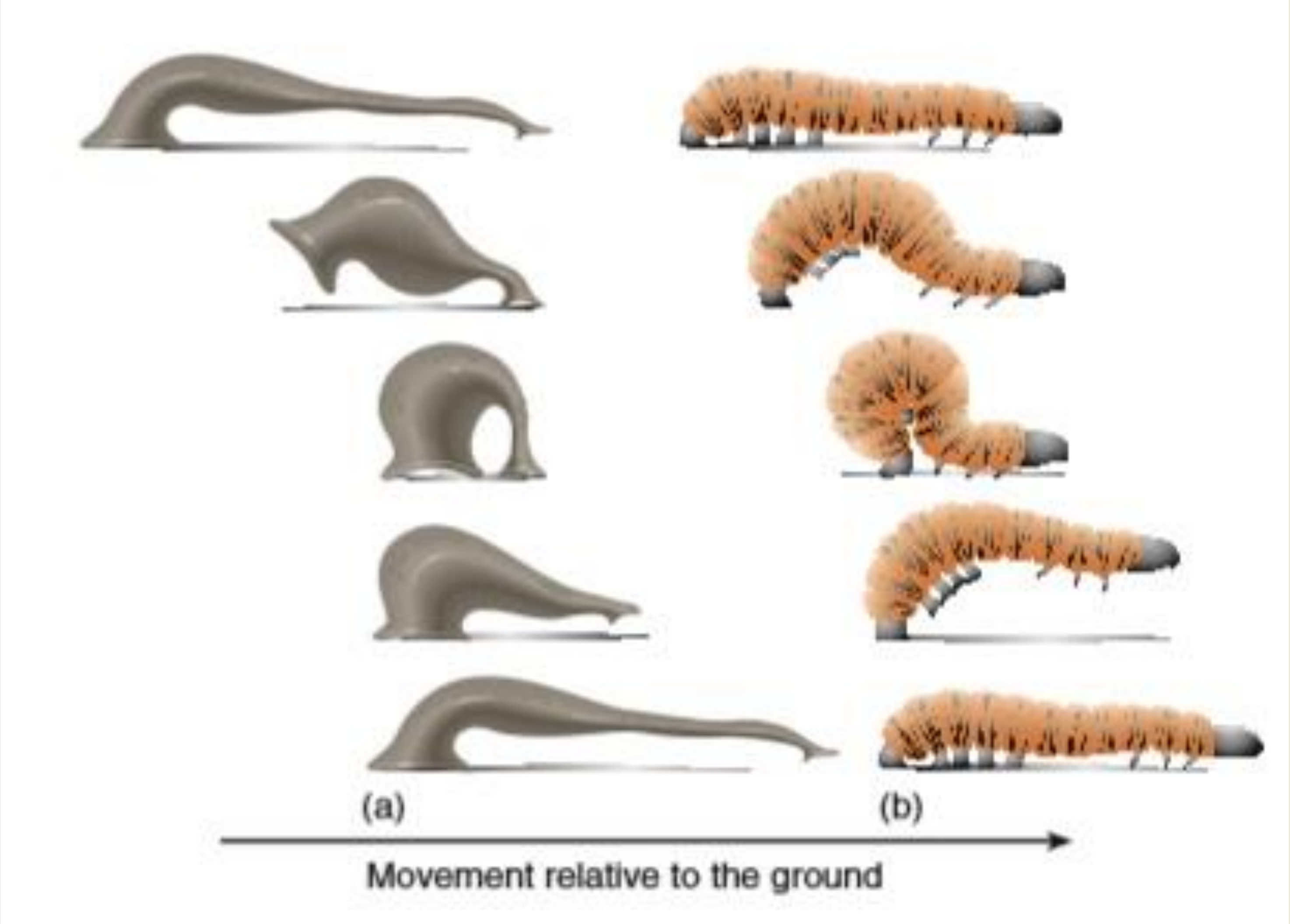


Fig: Looping Movements. (a) Leeches have anterior and posterior suckers, which they altenately attach to the substrate in looping movements to move forward. (b) Some insect larvae, such as lepidopteran caterpillars, exhibit similar movements. The caterpillar uses arching movements to move forward.

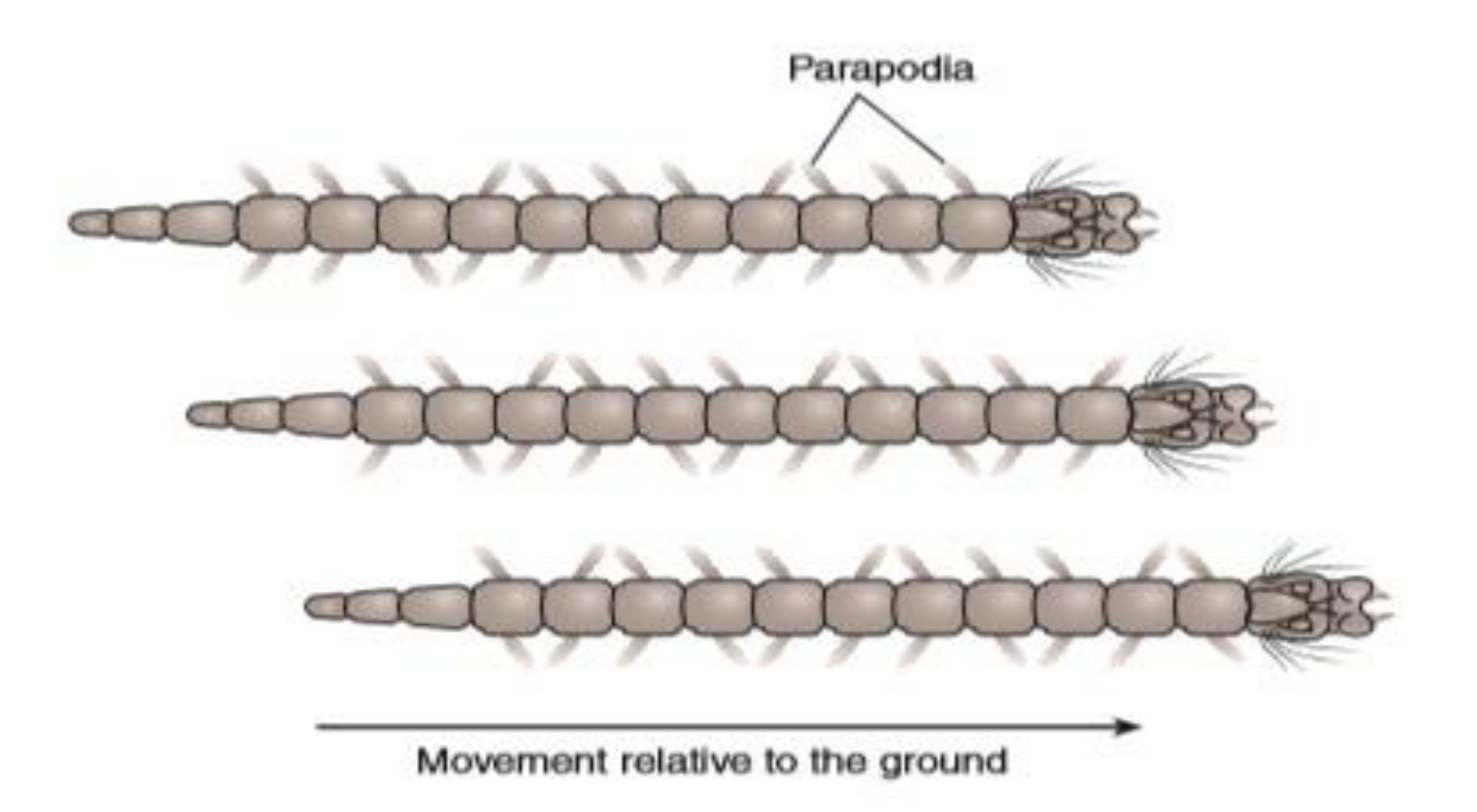


Fig: Locomotion in a Polychaete. When a polychaete (e.g., Nereis) crawls slowly, the tips of the multiple limbs (parapodia) move backward relative to the body. Since the tips of the parapodia touch the ground, this moves the body forward. In addition, a coordinated wave of activity in the parapodia passes forward from the tail to the head, with the left and right parapodia being exactly one-half wavelength out of phase. This ensures that each parapodium executes its power stroke without interfering with the parapodium immediately posterior. For simplification, setae movements are not shown.

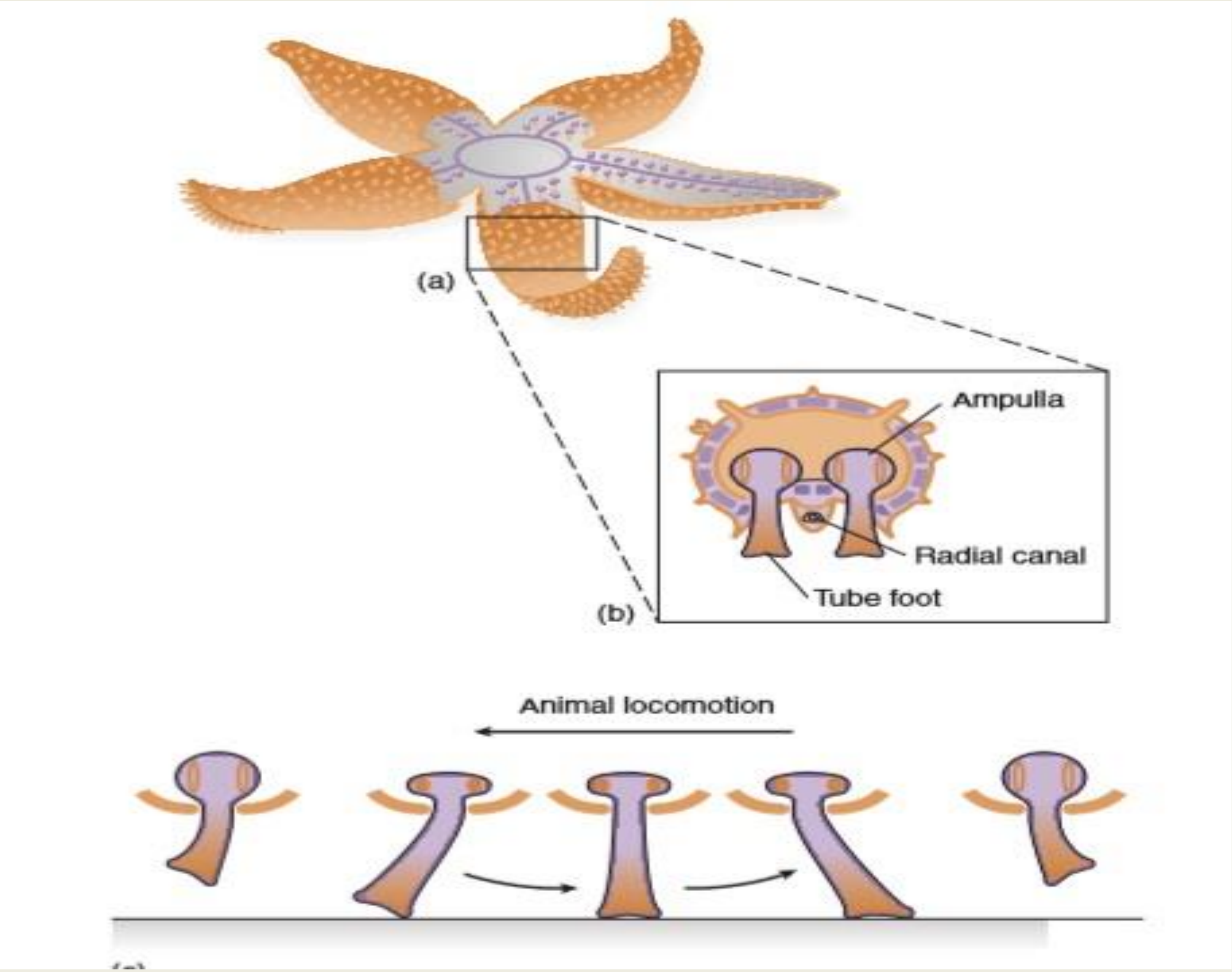


Fig: Water-Vascular System of Echinoderms. (a) General arrangement of the water-vascular system. (b) Cross section of an arm, showing the radial canal, ampullae, and tube feet of the water-vascular system. (c) Stepping cycle of a single tube foot. For simplification, the retractor muscles in the tube foot are not shown.

2) Terrestrial Locomotion in Invertebrates:

(Walking)

The walking limbs of the most highly evolved arthropods (Crustacea, Chelicerata, and Uniramia)

(Flight)

present-day insects exhibit a wide range of structural adaptations and mechanisms for flight

Jumping

insects
(fleas, grasshoppers, leafhoppers)

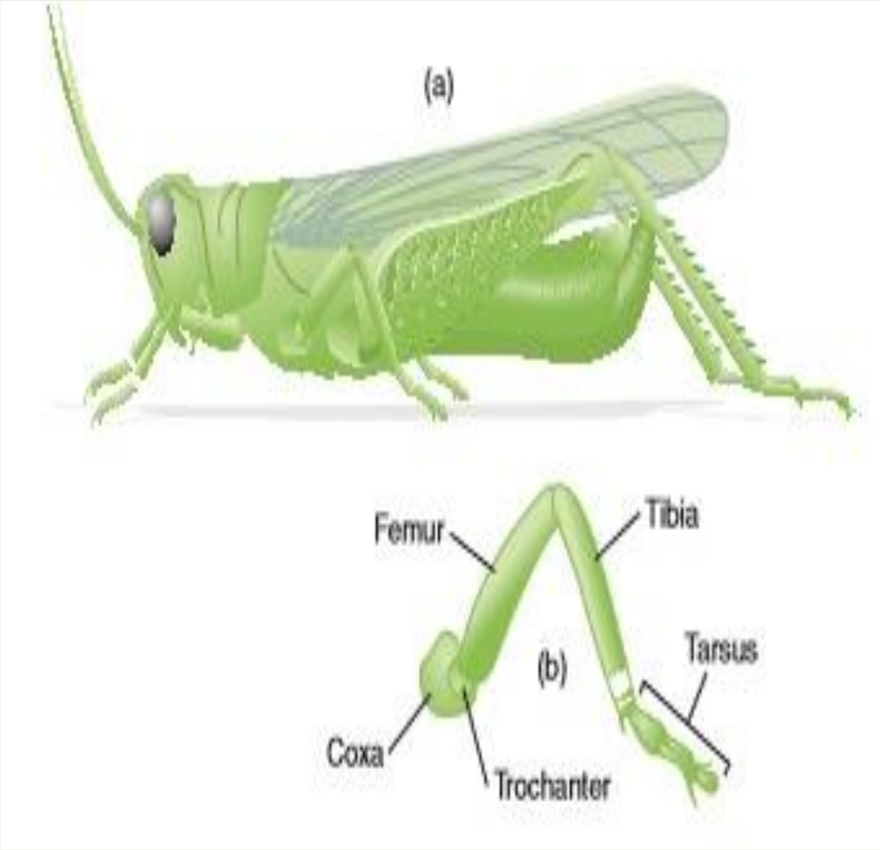


Fig: Typical Arthropod Limb. (a) Notice that most of the muscles are in the basal section. (b) Characteristic projection of the arthropod limb.

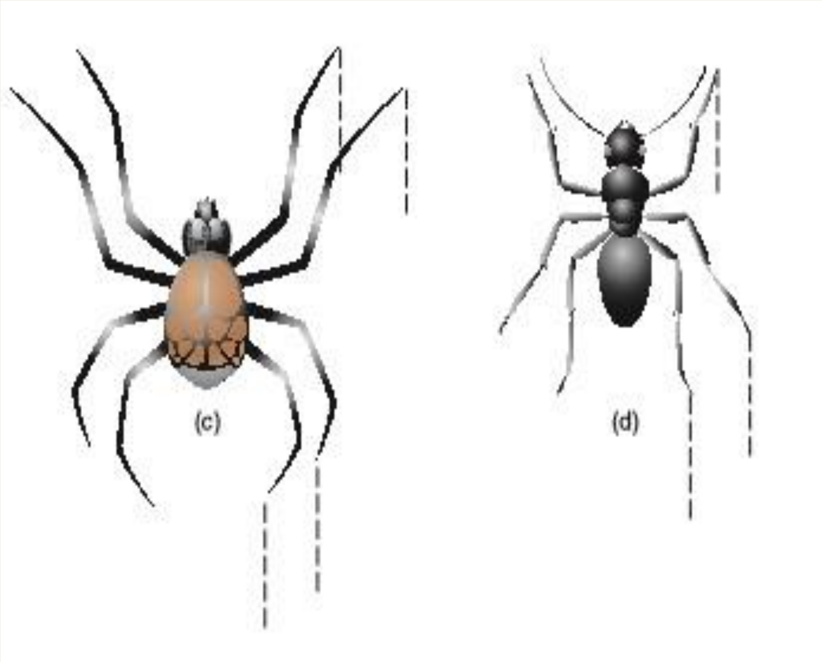


Fig: Walking, Limb Trajectories of Several Arthropods. (a) Crabs walk in a sideways fashion, a movement achieved by extension and retraction of the lower limb joints. Other arthropods, such as (b) the lobster, (c) the spider, and (d) an insect, have nonoverlapping limb trajectories and move forward by rotating the basal joint of the limb relative to their body.

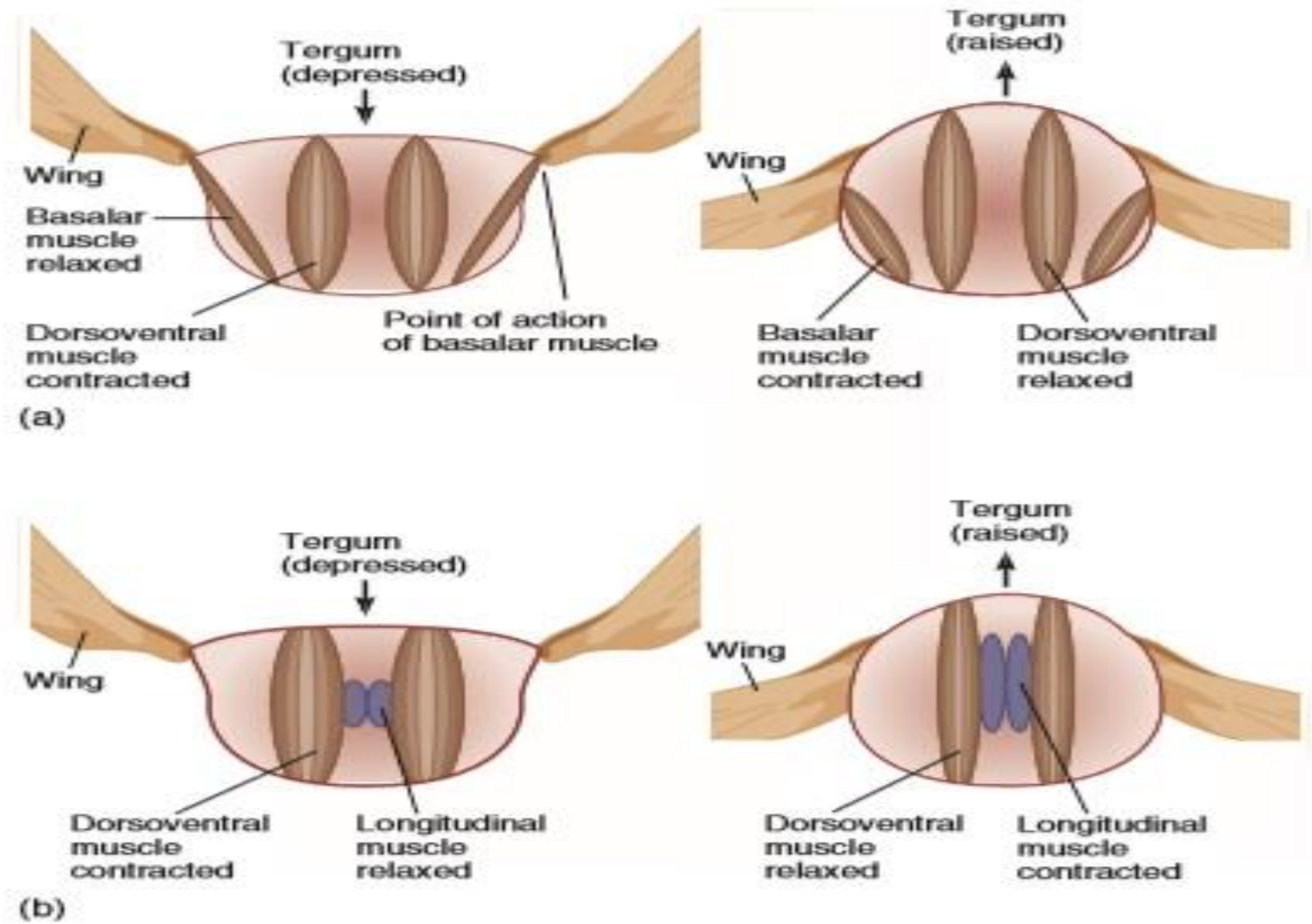


Fig: Insect Flight. (a) Muscle arrangements for the direct or synchronous flight mechanism. Note that muscles responsible for the downstroke attach at the base of the wings. (b) Muscle arrangements for the indirect or asynchronous flight mechanism. Muscles changing the shape of the thorax cause wings to move up and down.

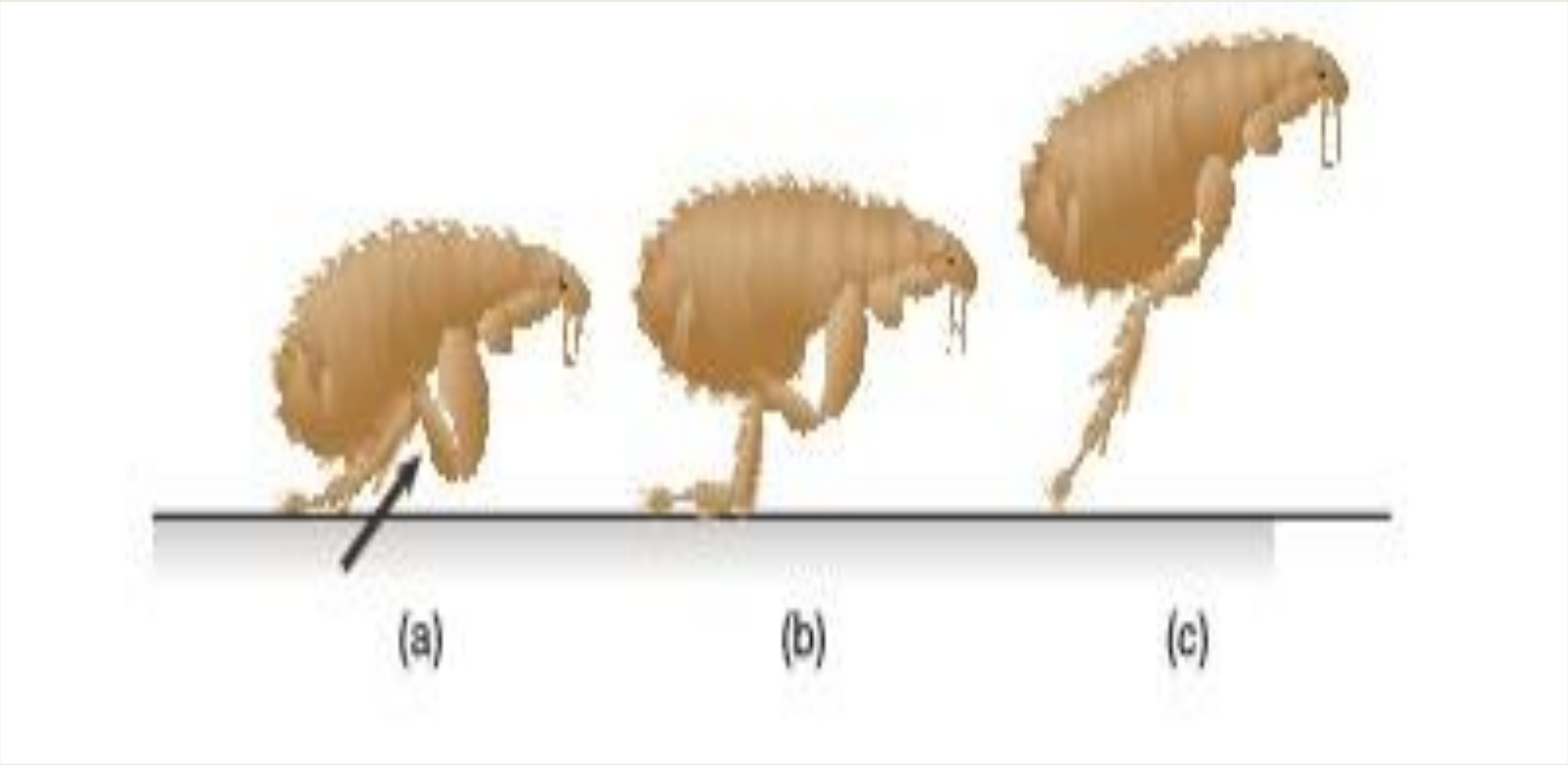


Fig: Jump of Flea. A flea has a jointed exoskeleton. (a) When a flea is resting, the femur (black arrow) of the leg (for simplicity, only one leg is shown) is raised, the joints are locked, and energy is stored in the deformed elastic protein (“animal rubber’’ or resilin) of the cuticle. (b) As a flea begins to jump, the relaxation of muscles unlocks the joints. (c) The force exerted against the ground by the tibia gives the flea a specific velocity that determines the height of the jump. The jump is the result of the explosive release of the energy stored in the resilin of the cuticle.

THE MUSCULAR SYSTEM OF VERTEBRATES

- The vertebrate endoskeleton provides sites for skeletal muscles to attach. **Tendons**, which are tough, fibrous bands or cords, attach skeletal muscles to the skeleton.
- Most of the musculature of fishes consists of segmental **myomeres** (Gr. myo, muscle meros, part)

The transition from water to land entailed changes in:

- ✓ body musculature
- ✓ the appendages became increasingly important in locomotion.
- ✓ movements of the trunk became less important
- ✓ Lost of segmental nature of the myomeres in the trunk muscles.

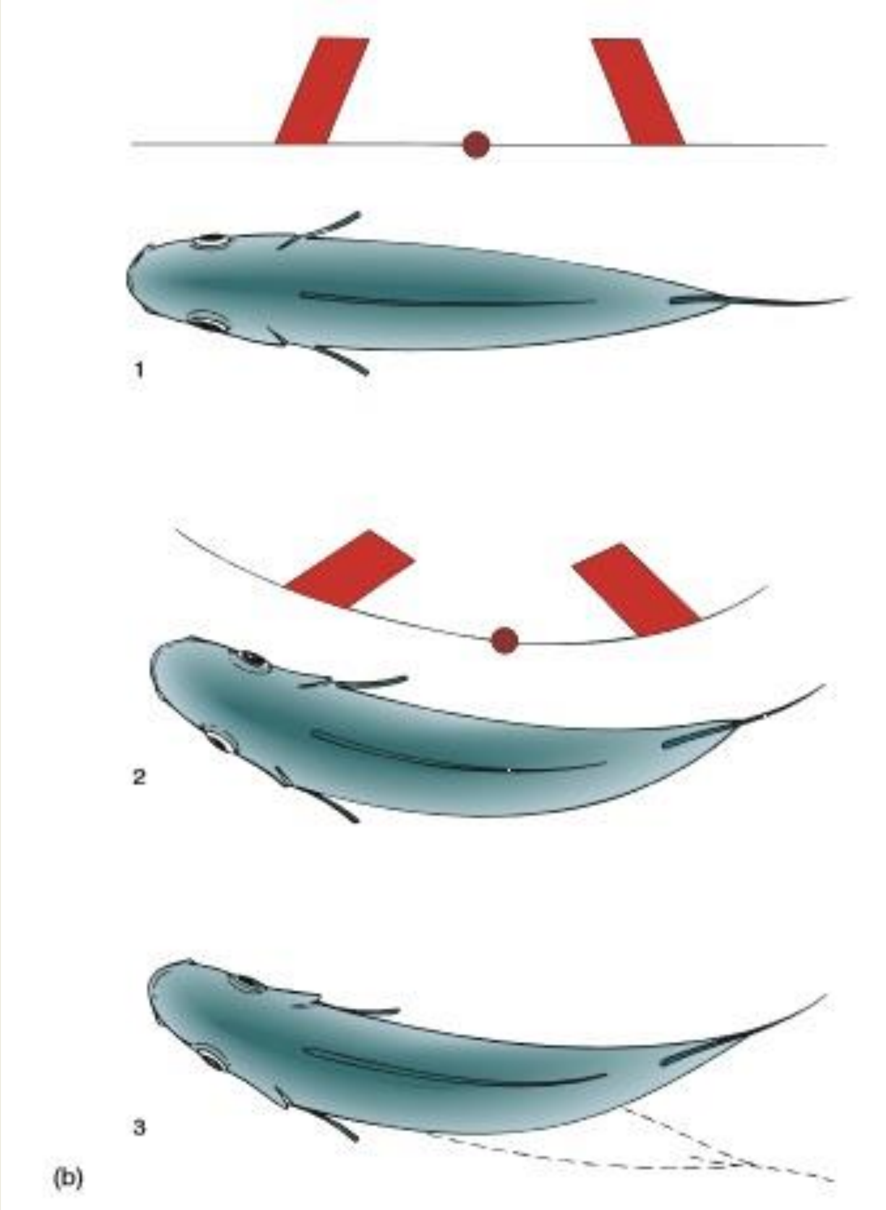


Fig: Fish Musculature. (a) Skeletal muscles of a bony fish (perch), showing mainly the large muscles of the trunk and tail. These muscles occur in blocks called myomeres separated by connective tissue sheaths. Notice that the myomeres are flexed so that they resemble the letter W tipped at a 90° angle. The different colors (red, orange, blue) represent different myomeres. (b) Fish movements based on myomere contractions. (1) Muscular forces cause the myomere segments to rotate rather than constrict. (2) The rotation of cranial and caudal myomere segments bends the fish's body about a point midway between the two segments. (3) Alternate bends of the caudal end of the body propel the fish forward.

Skeletal Muscle Contraction

- ✓ The striation in each muscle fiber arises from the alternating dark and light bands of the many smaller, threadlike **myofibrils.**
- ✓ These bands are due to the placement of the muscle proteins **actin** and **myosin** within the myofibrils.
- ✓ Myosin occurs as thick filaments and actin as thin filaments.
- ✓ the lightest region of a myofibril (**the I band**) contains only actin.
- ✓ darkest region (**the A band**) contains both actin and myosin.
- ✓ The functional (contractile) unit of a myofibril is the **sarcomere**, each of which extends from one Z line to another Z line.
- ✓ When a sarcomere contracts, the actin filaments slide past the myosin filaments as they approach one another.

- ✓ The combined decreases in length of the individual sarcomeres account for contraction of the whole muscle fiber, and in turn, the whole muscle.
- ✓ This movement of actin in relation to myosin is called the **sliding-filament model of muscle contraction.**
- ✓ Myosin contains globular projections that attach to actin at specific active binding sites, forming attachments called **cross-bridges.**
- ✓ Once crossbridges form, they exert a force on the thin actin filament and cause it to move.

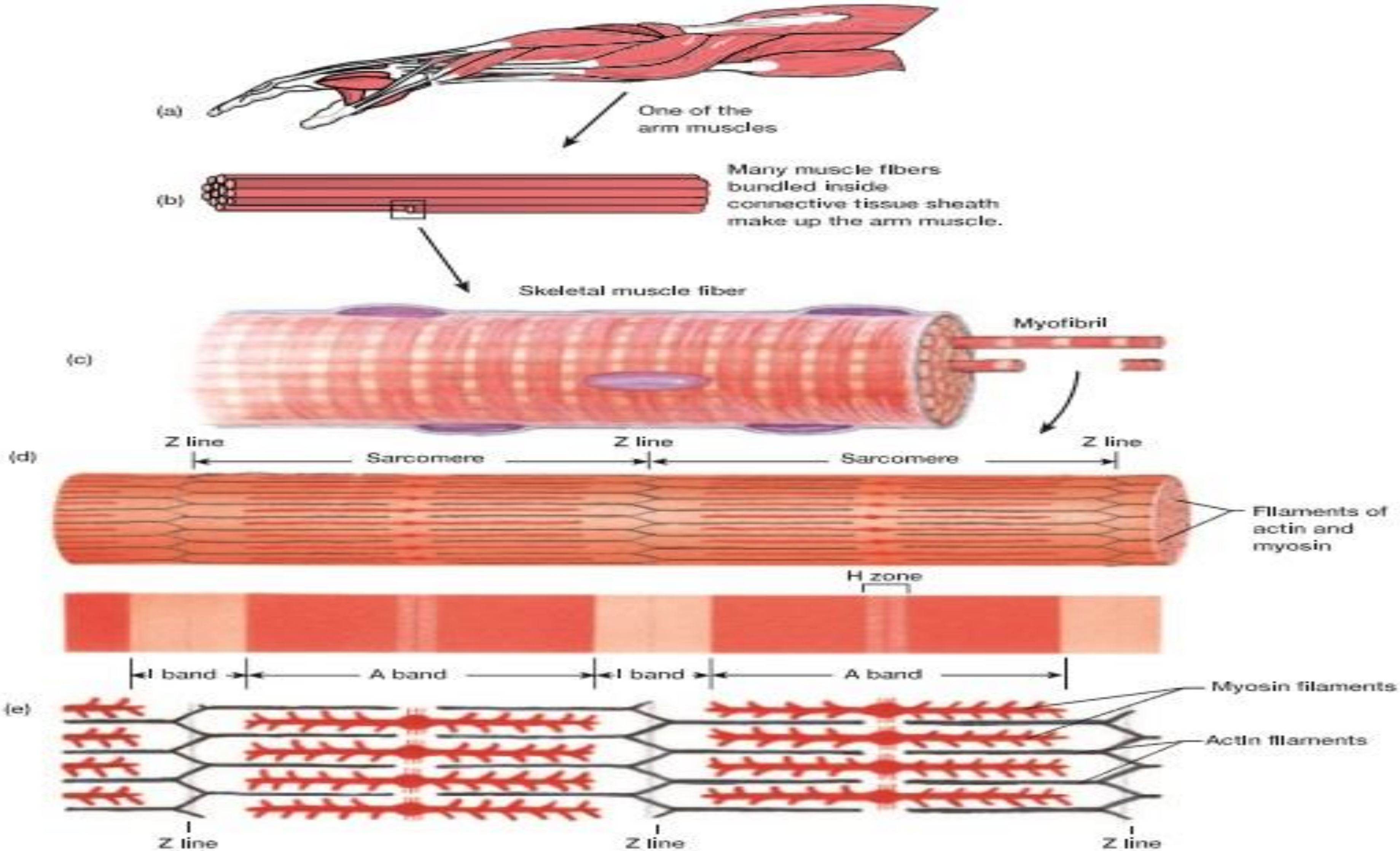


Fig: Structure of Skeletal Muscle Tissue. (a) A skeletal muscle in the forearm consists of many muscle fibers (cells) (b) bundled inside a connective tissue sheath. (c) A skeletal muscle fiber contains many myofibrils, each consisting of (d) functional units called sarcomeres. (e) The characteristic striations of a sarcomere are due to the arrangement of actin and myosin filaments.

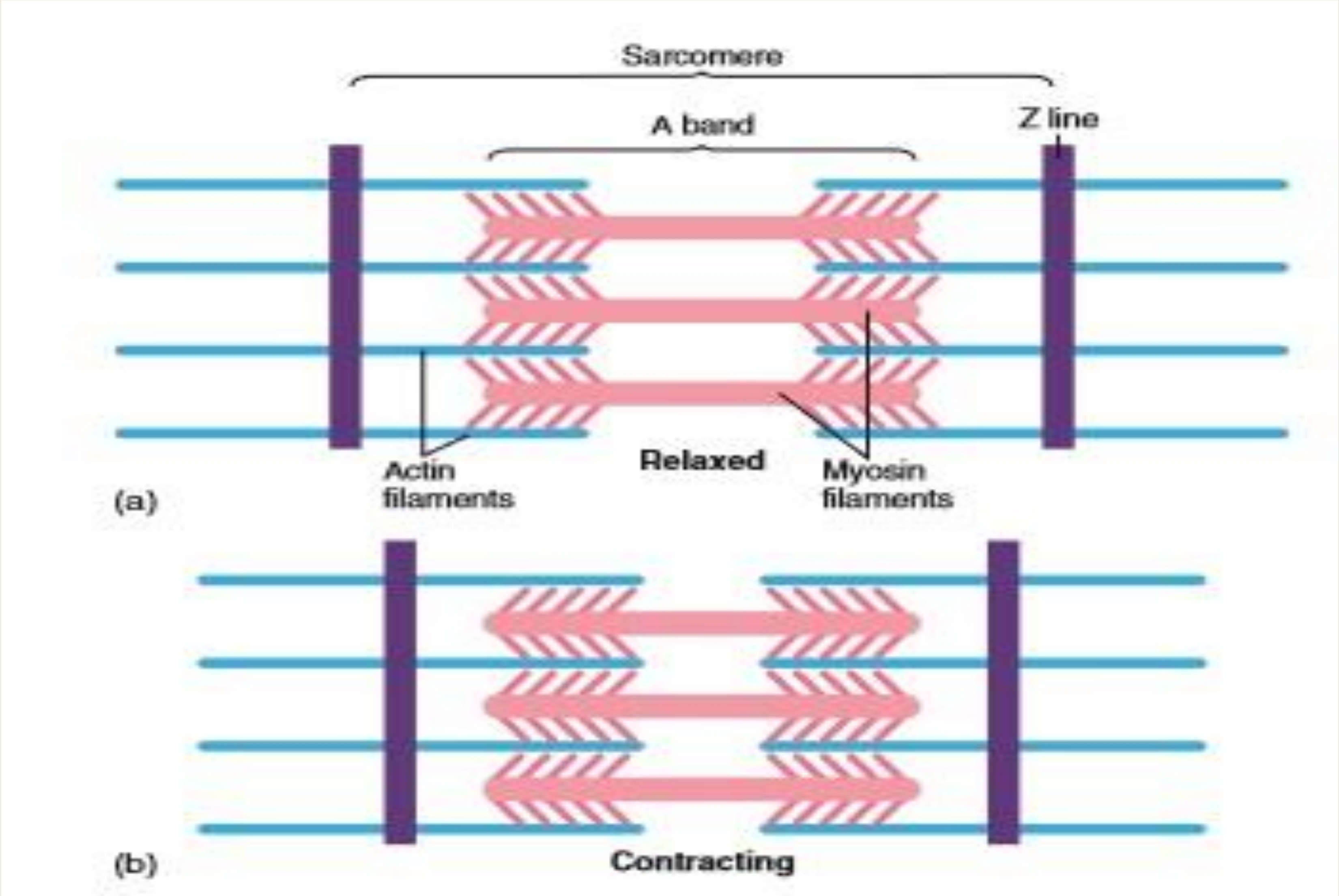


Fig: Sliding-Filament Model of Muscle Contraction. (a) A sarcomere in a relaxed position. (b) As the sarcomere contracts, the myosin filaments form attachments called cross-bridges to the actin filaments and pull the actin filaments so that they slide past the myosin filaments. Compare the length of the sarcomere in (a) to that in (b).

Control of Muscle Contraction:

Arrangement of structures :

- ✓ When a motor nerve conducts nerve impulses to skeletal muscle fibers, the fibers are stimulated to contract via a motor unit.
- ✓ A **motor unit** consists of one motor nerve fiber and all the muscle fibers with which it communicates.
- ✓ A space separates the specialized end of the motor nerve fiber from the membrane (**sarcolemma**)of the muscle fiber.
- ✓ The **motor end plate** is the specialized portion of the sarcolemma of a muscle fiber surrounding the terminal end of the nerve.
- ✓ This arrangement of structures is called a **neuromuscular junction or cleft.**

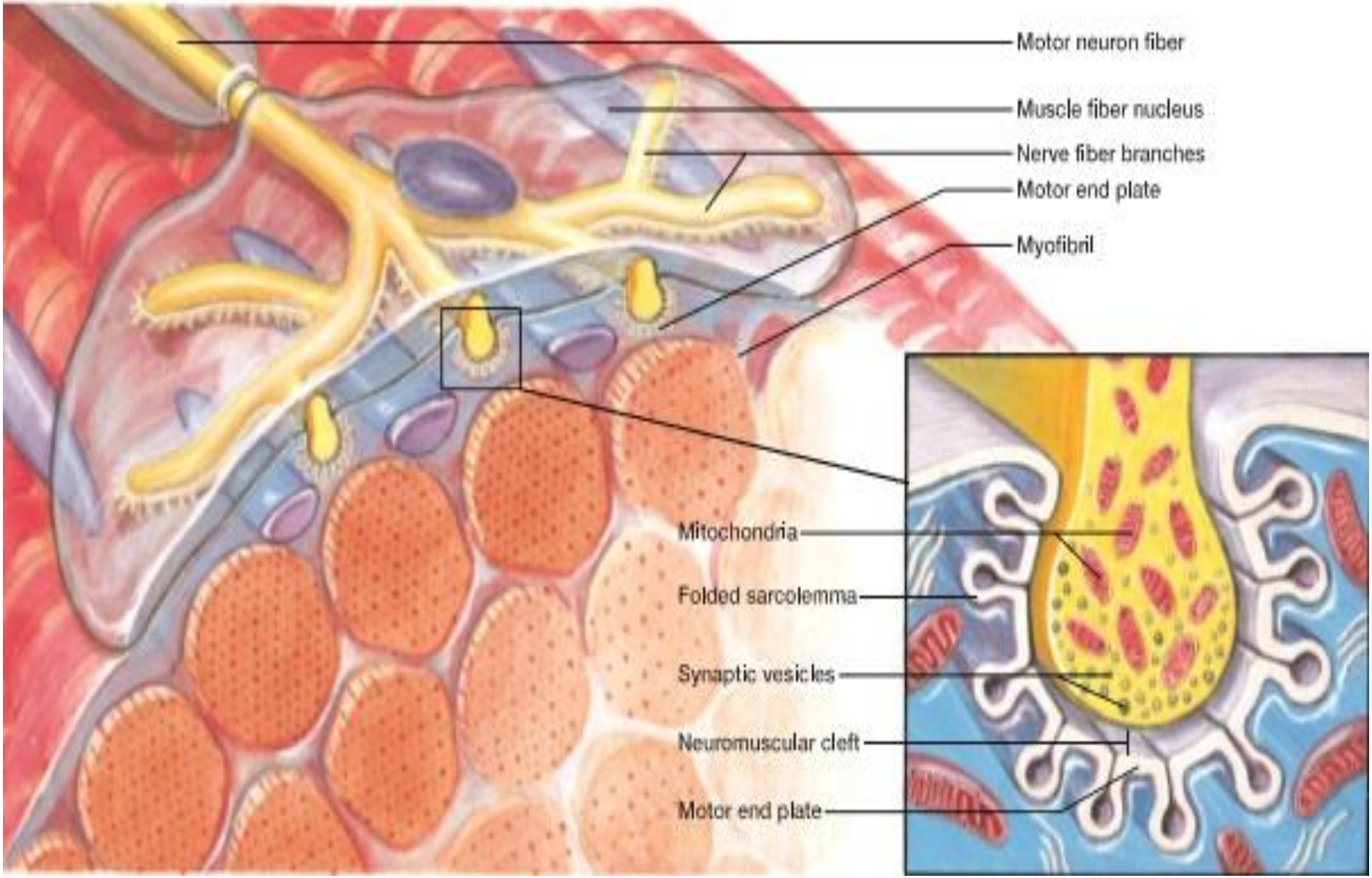


Fig: Nerve-Muscle Motor Unit. A motor unit consists of one motor nerve and all the muscle fibers that it innervates. A neuromuscular junction, or cleft, is where the nerve fiber and muscle fiber meet.

Steps of skeletal muscle contraction:

- When nerve impulses reach the ends of the nerve fiber branches, synaptic vesicles in the nerve ending release a chemical called **acetylcholine.**

↓

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↓

- **When acetylcholine binds to the receptors, ions are redistributed on both sides of the membrane, and the polarity is altered.**

↓

- **This altered polarity flows in a wavelike progression into the muscle fiber by conducting paths called transverse tubules.**

↓

- The altered polarity of the transverse tubules causes the sarcoplasmic reticulum to release calcium ions (Ca2), which diffuse into the cytoplasm

- The calcium then binds with a regulatory protein called **troponin** that is on another protein called **tropomyosin**

- This binding exposes the myosin binding sites on the actin molecule that tropomyosin had blocked

- Power strokes of cross-bridges result in filament sliding and muscular contraction.

- Relaxation follows contraction. During relaxation, an active transport system pumps calcium back into the sarcoplasmic reticulum for storage.