Muscle Physiology

Muscle Tissues

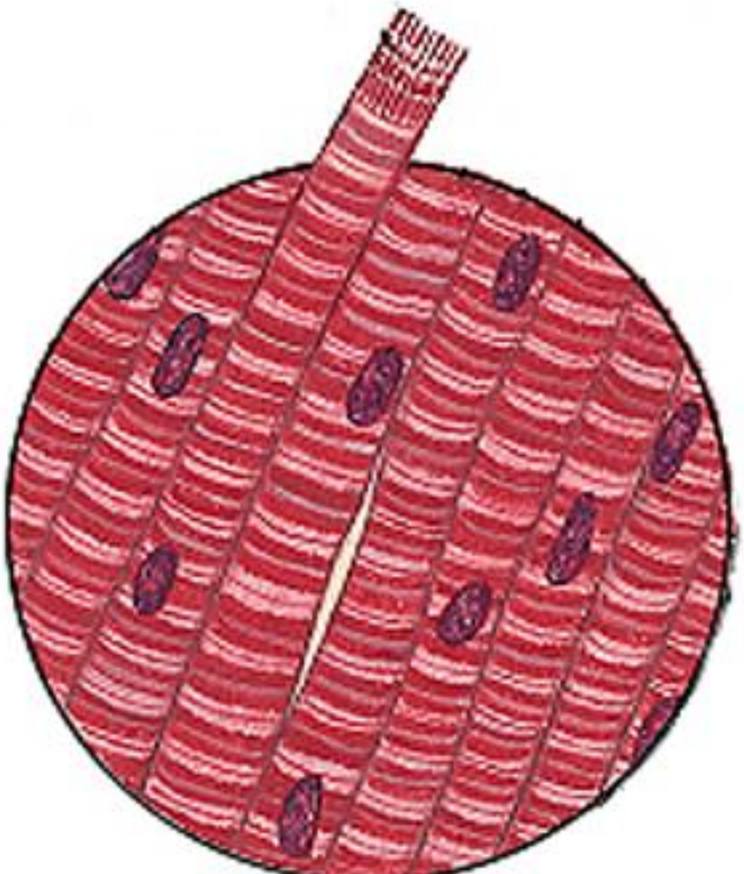
The anatomy of fish muscle is different from the anatomy of terrestrial mammals, fish lacks the tendinous system which connect muscle bundles to the bony skeleton of the animal.

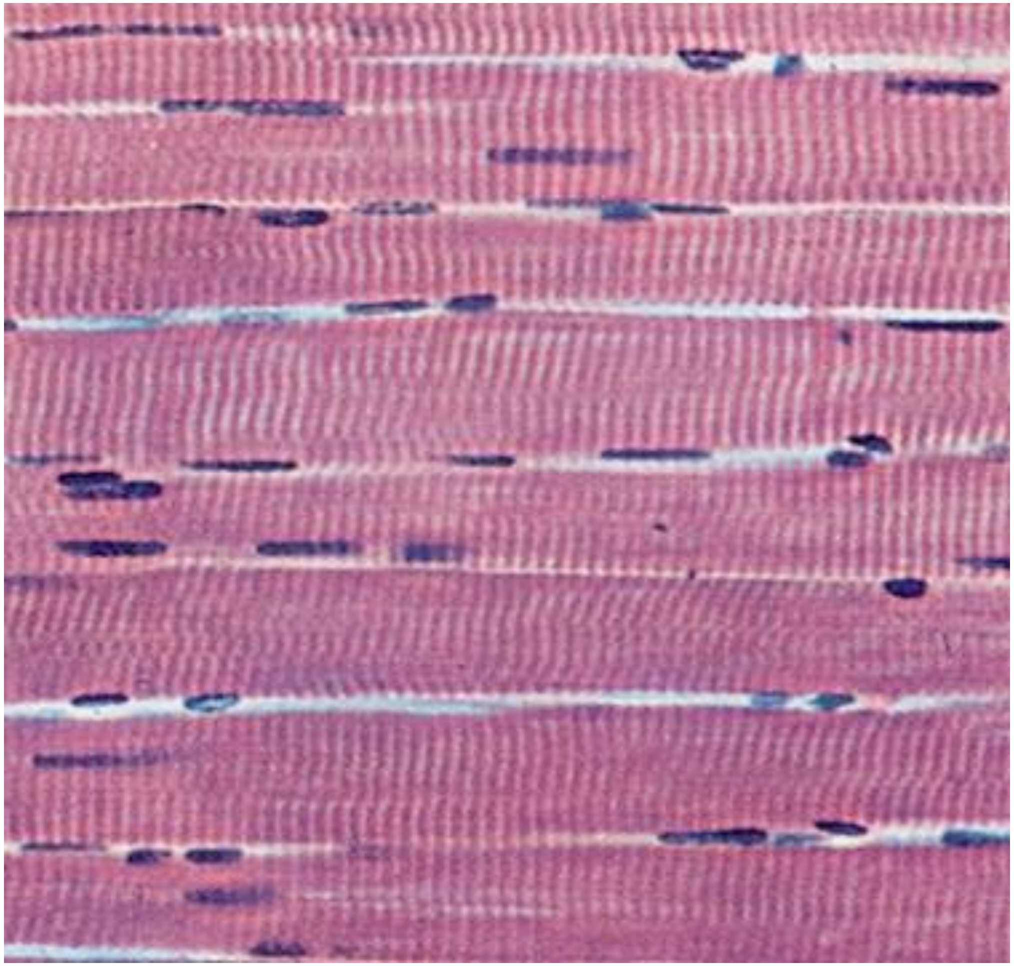
Skeletal – striated, multinucleate, voluntary

Smooth - found in walls of hollow visceral organs; ex. stomach, bladder, respiratory passages; visceral, non-striated, involuntary

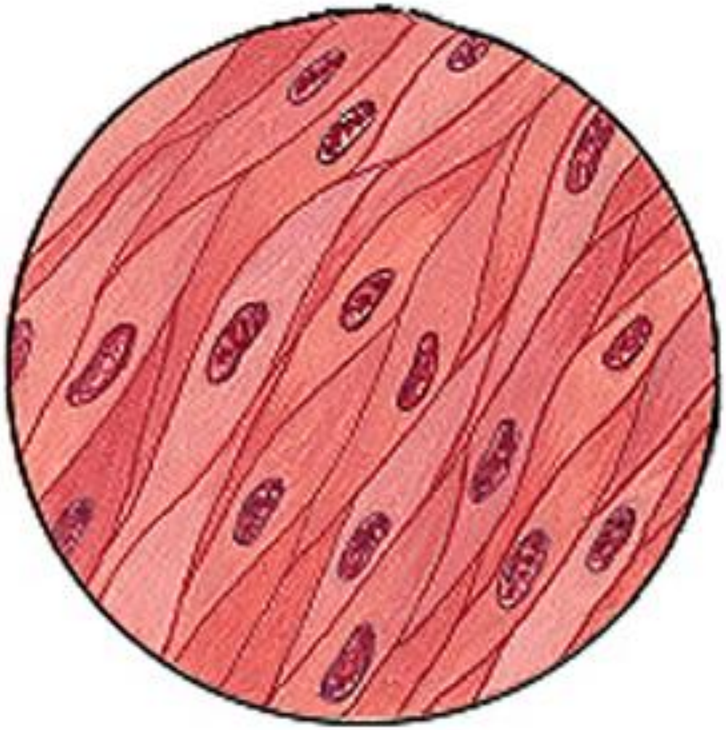
Cardiac – in heart only, striated, involuntary,

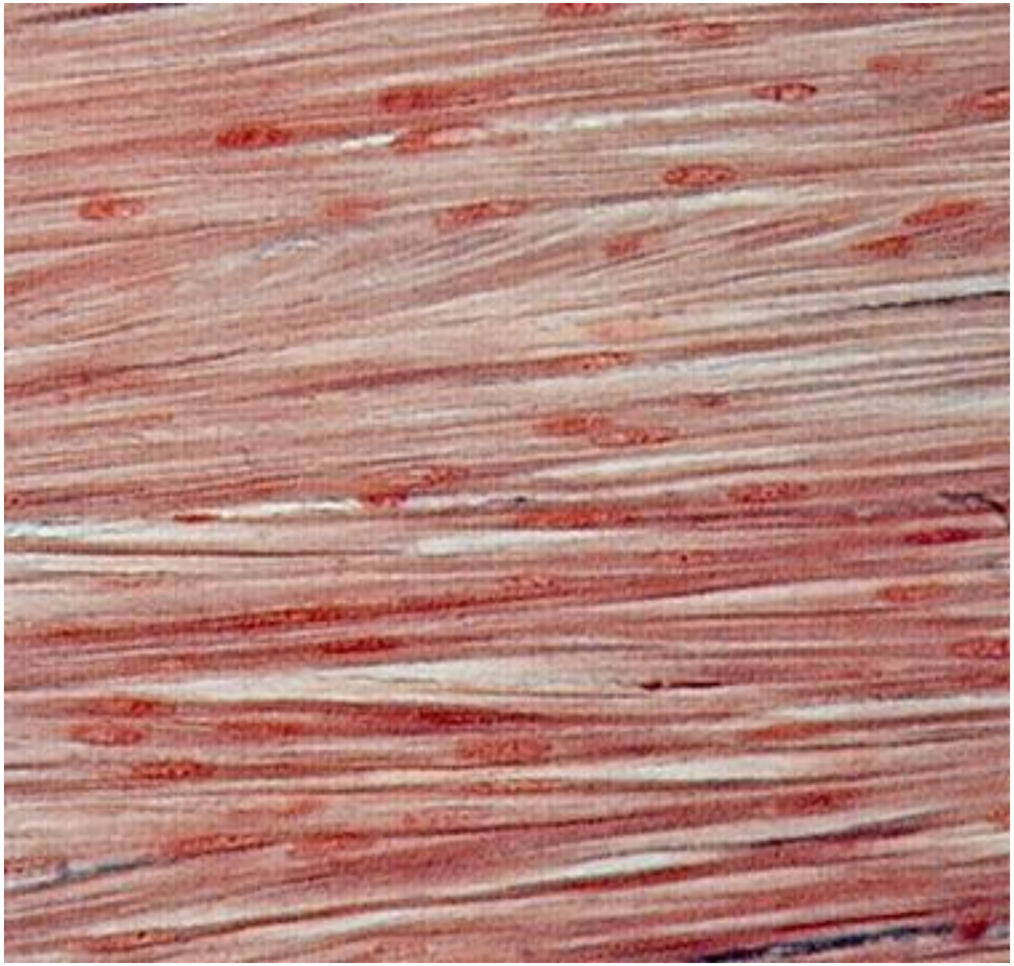
Skeletal Muscle Tissue



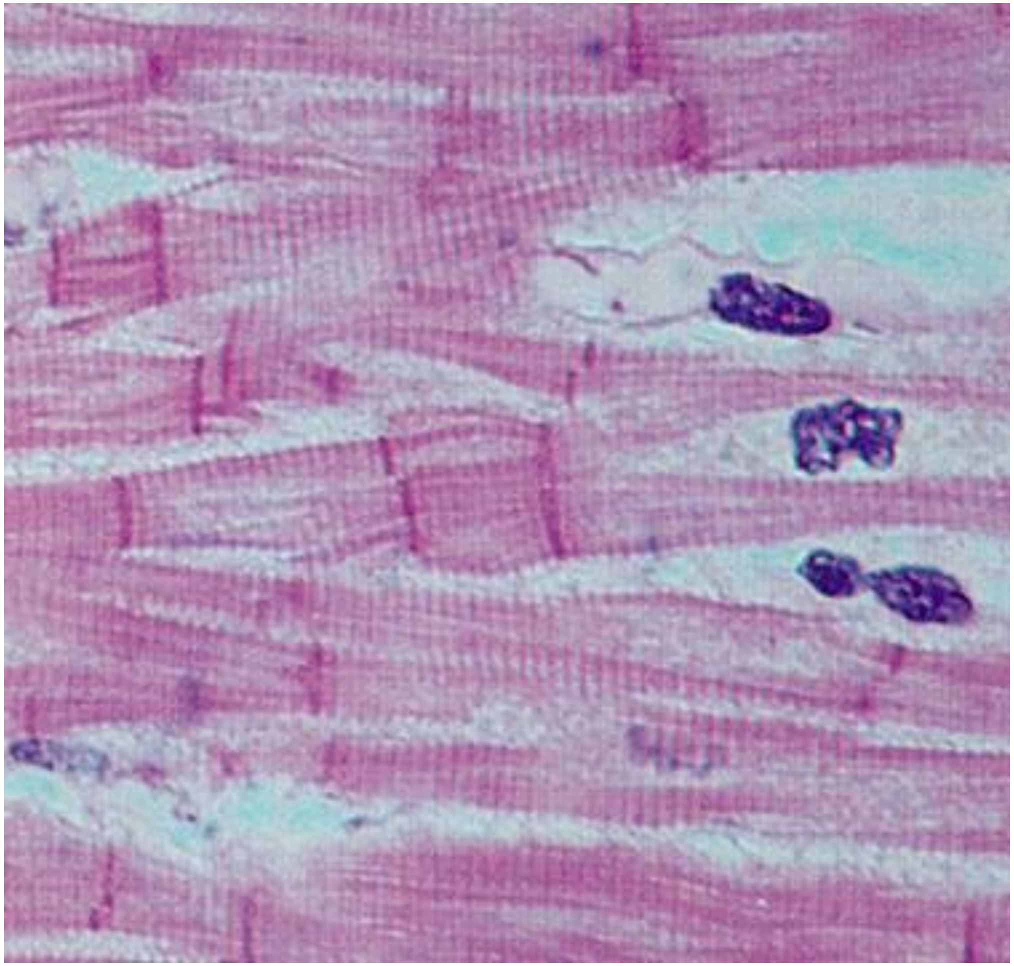


Smooth Muscle Tissue





Cardiac Muscle Tissue

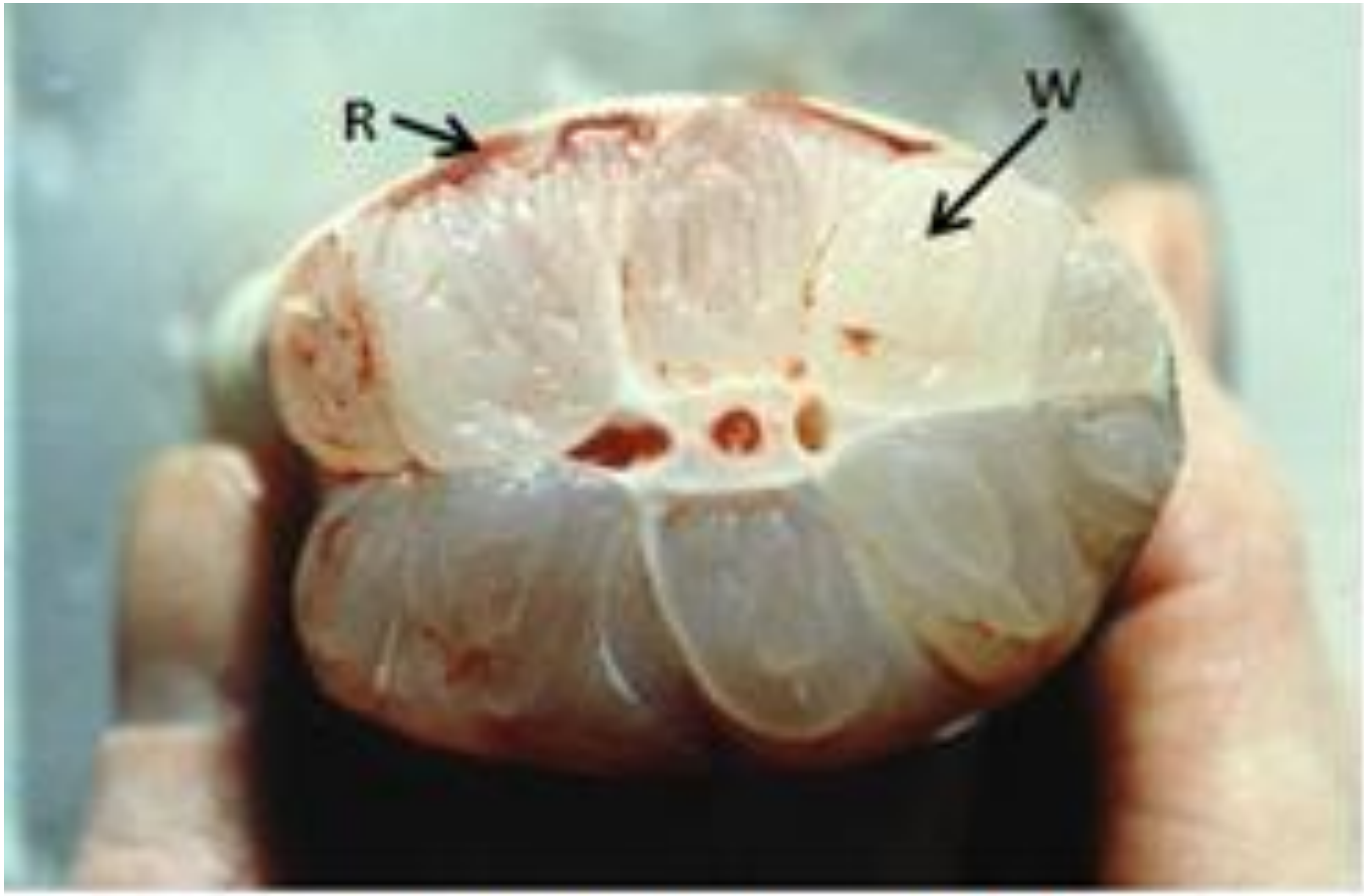


Skeleton Muscle in Fishes

Fish has muscle cells running in parallel and connected to sheaths of connective tissue (**myocommata**), which are anchored to the skeleton and the skin. The bundles of parallel muscle cells are called **myotomes**

- The skeleton of myotomal muscle can be divided into two principal types, **fast twitch or white muscle**, and **slow or red muscle**
- **Fast muscle makes up the bulk of the fish**, typically 80–100 % of the fish cross section at a given point
- The proportion of slow muscle is related to the ecology of the fish: **constantly swimming pelagic species have more slow muscle than benthic species**
- The slow muscle is usually confined to a zone beneath the lateral line, making up an increasing proportion of the body cross-section towards the tail

White & Red Muscles



Cross-section showing red (R) and white (W) fibres

White & Red Muscles

Most fish muscle tissue is white but, depending on the species, many fish will have a certain amount of dark tissue of reddish colour

The dark muscle is located just under the skin along the side of the body.

The proportion of dark to light muscle varies with the activity of the fish. In pelagic fish, i.e., species such as herring and mackerel which swim more or less continuously, up to 48 % of the body weight may consist of dark muscle.

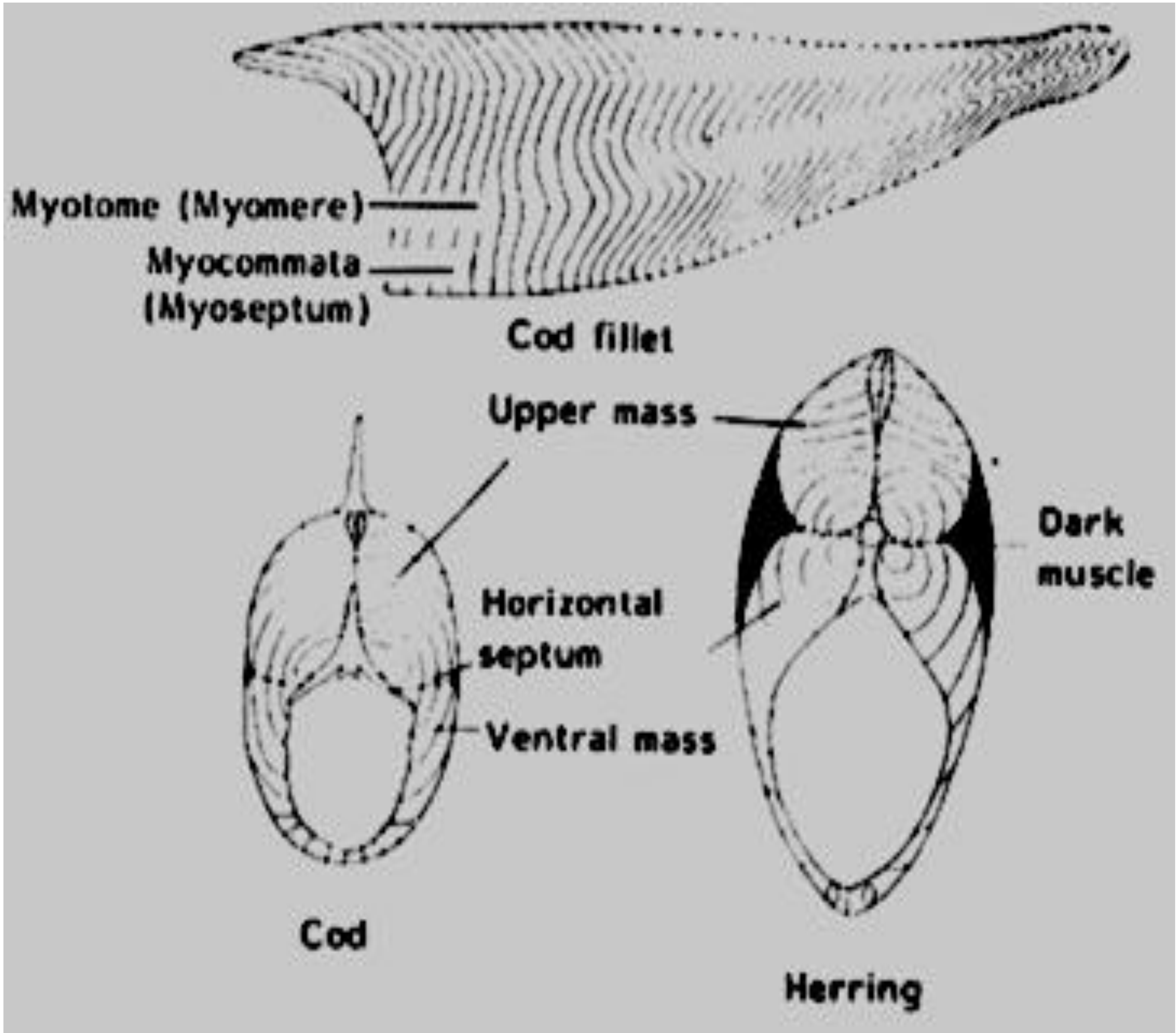
In demersal fish, i.e., species which feed on the bottom and only move periodically, the amount of dark muscle is very small.

There are many differences in the chemical composition of the two muscle types, like higher levels of lipids and myoglobin in the dark muscle.

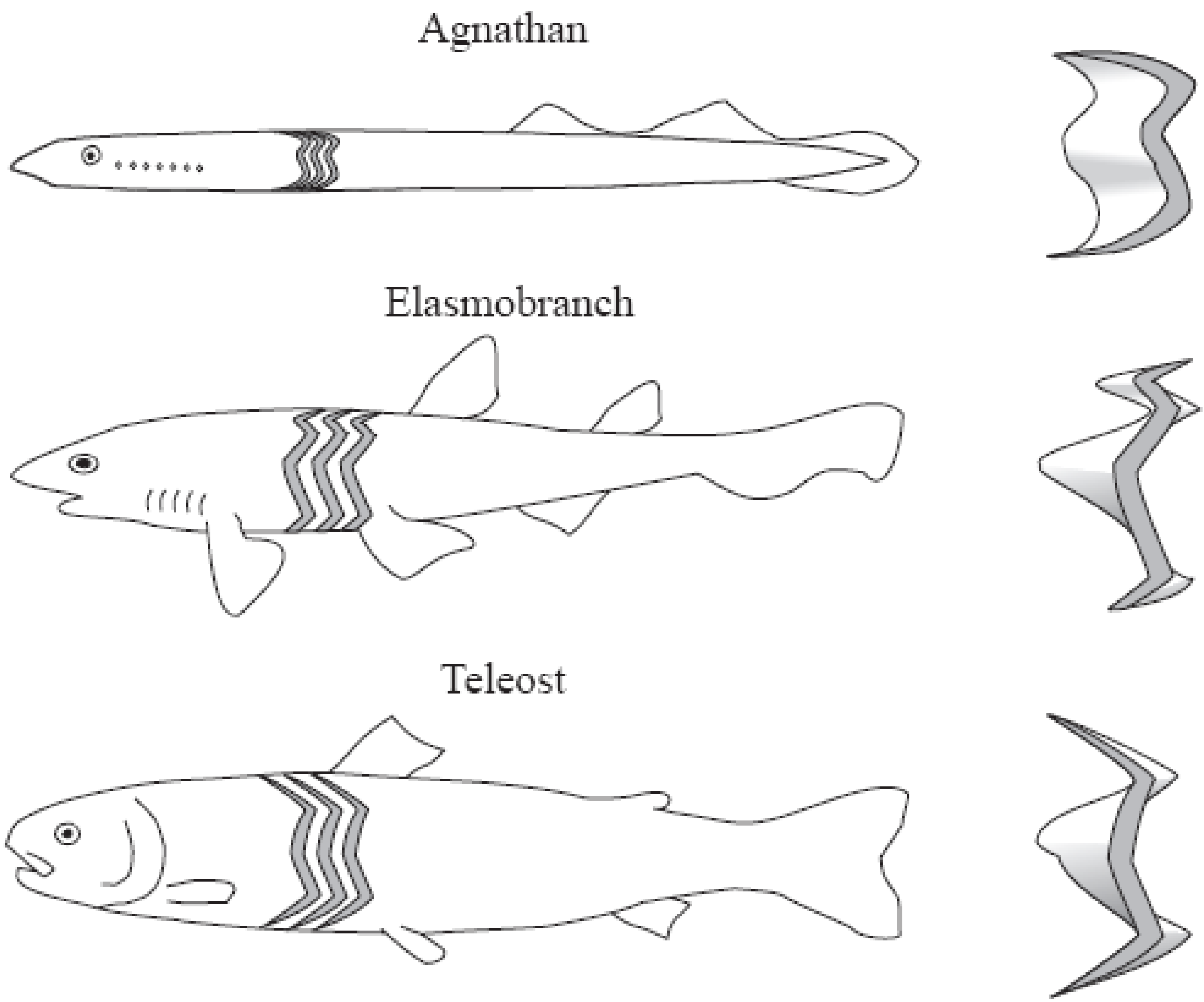
The parallel running myomeres/myotome are W shaped and alternatively arranged with myocommata or myosepta and serve as origins and insertion points for myomeres muscle

- Myomeres are divided into dorsal & ventral masses by a horizontal septum that extends between the transverse processes of the vertebrae:
  - **EPAXIALS** = above the septum
  - **HYPAXIALS** = below the septum
- Mid dorsal & midventral septa separate the myomeres of the 2 sides of the body. The midventral septum is called the **LINEA ALBA**.

Arrangement of Myomeres or Myotome

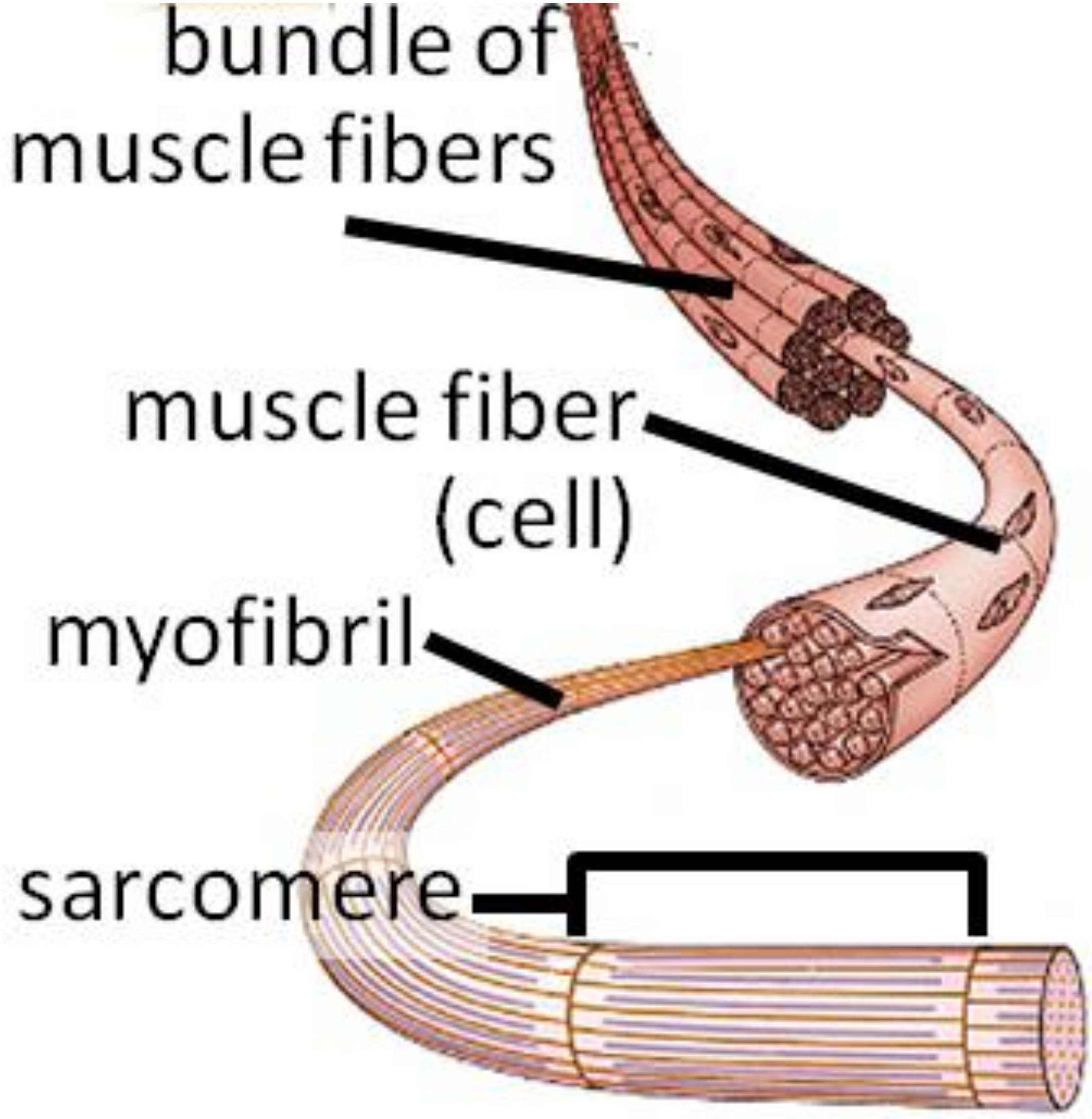


Shape of Myomere



Myotomal structure of the lateral muscle. Isolated myotomes are shown to the right of the fish.

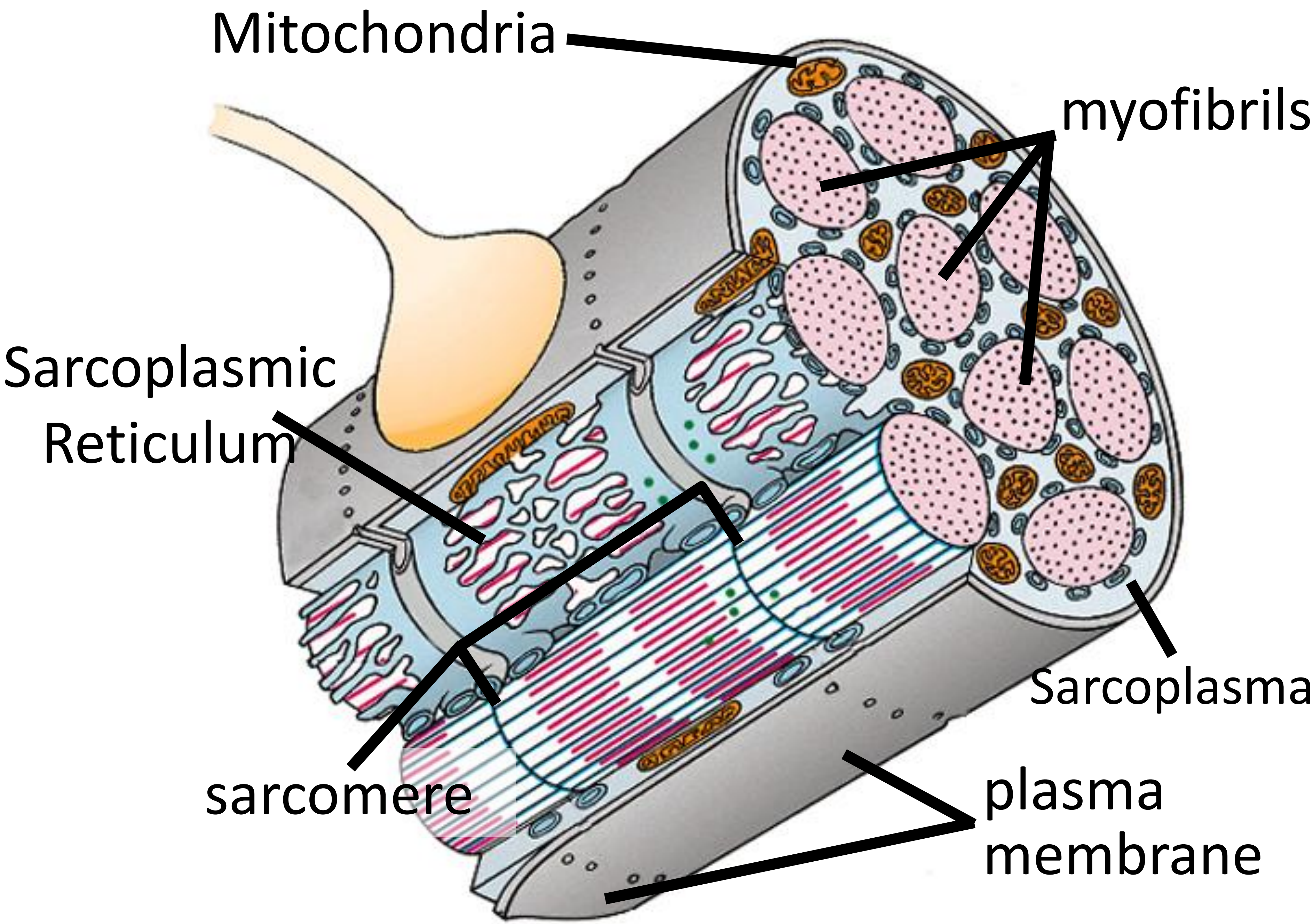
Skeleton Muscle Anatomy



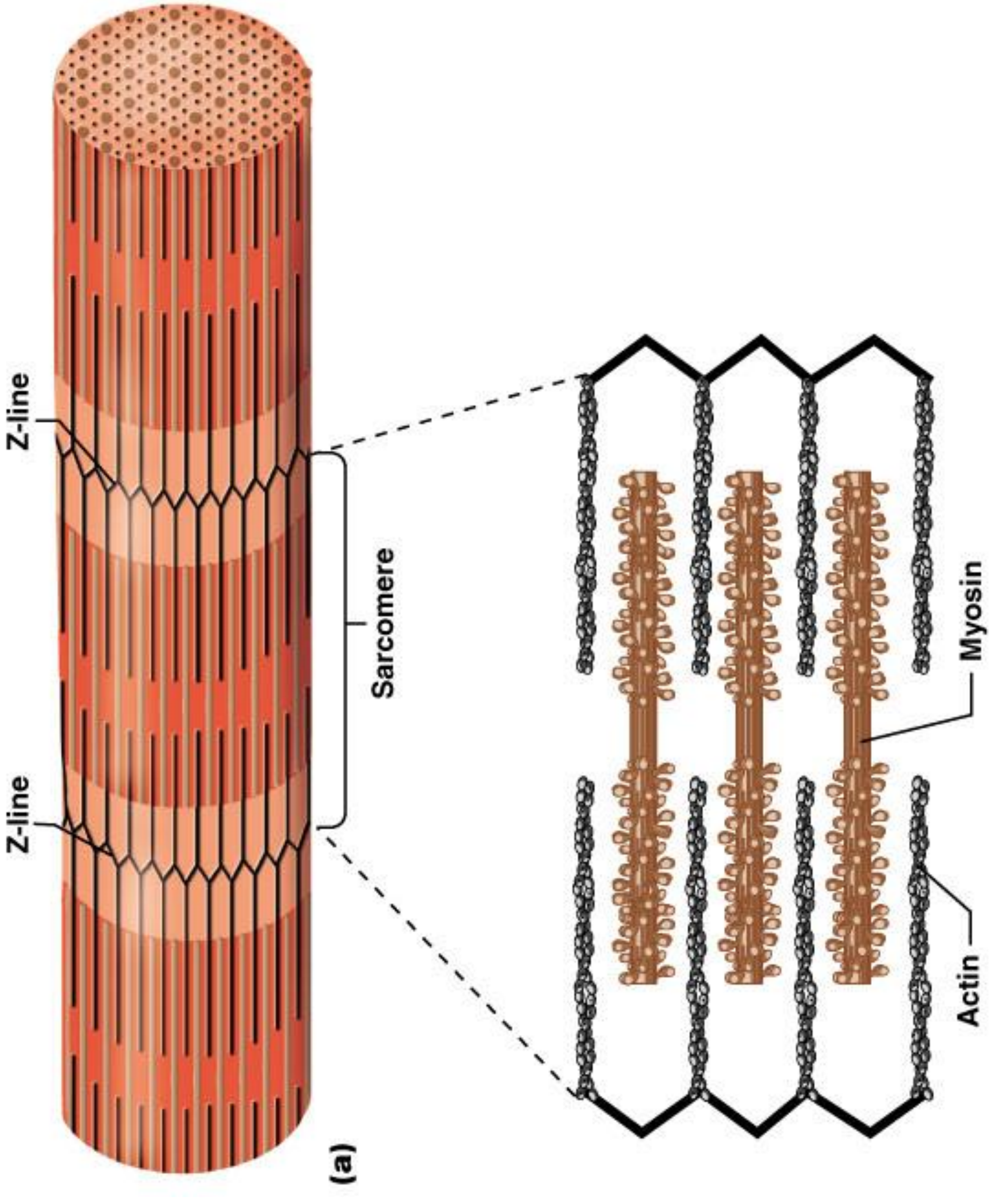
Fish muscle anatomy is ideally suited for the flexing muscle movements necessary for propelling the fish through the water

Skeleton Muscle Cell

The skeleton muscle tissue of fish is composed of striated muscle. The functional unit, i.e., **the muscle cell**, consists of **sarcoplasma** containing **nuclei, glycogen grains, mitochondria, sarcoplasmic reticulum** etc., and a number (up to 1 000) of **myofibrils**. The cell is surrounded by a sheath of connective tissue called the **sarcolemma**. The myofibrils contain the contractile proteins, **actin** and **myosin**. These proteins or filaments are arranged in a characteristic alternating system making the muscle appear striated upon microscopic examination

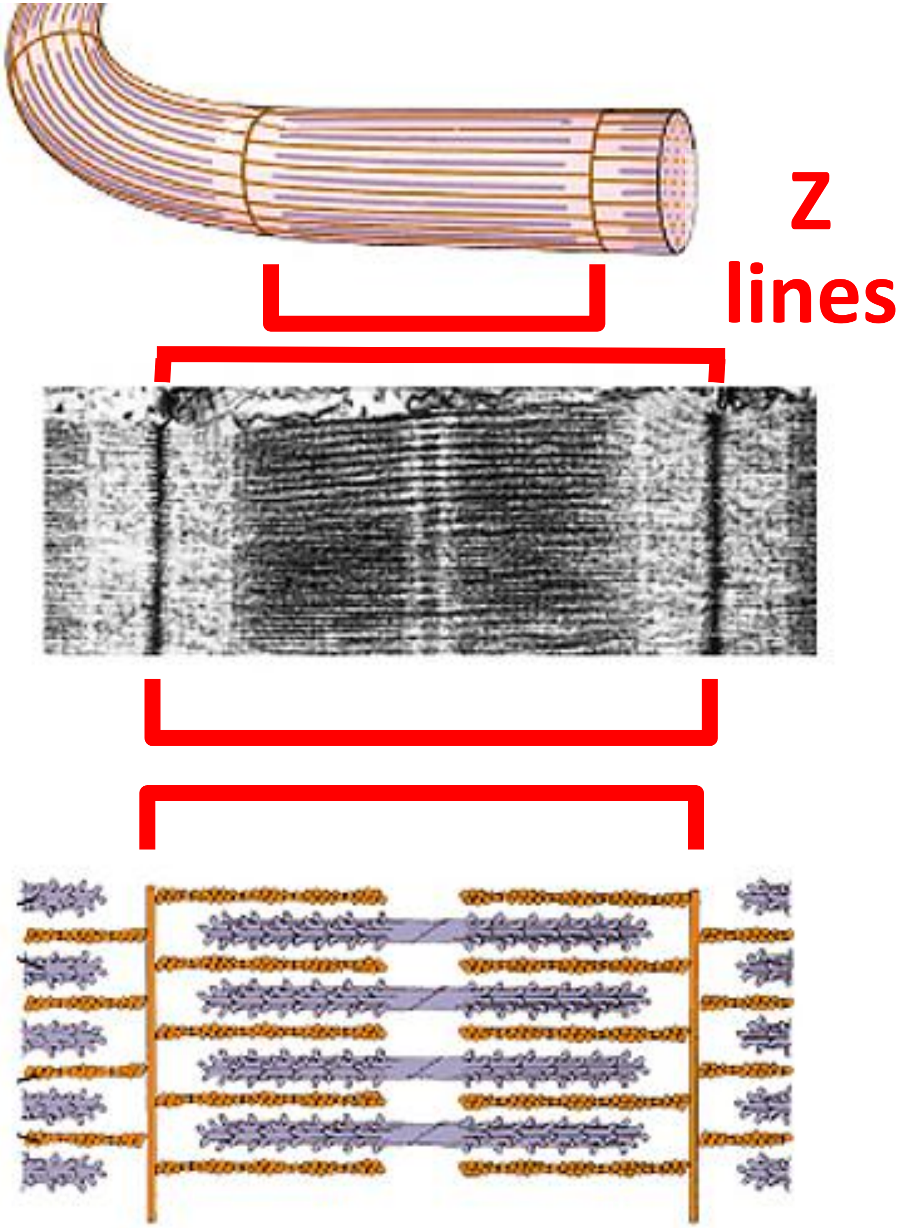


Mitochondria
myofibrils
Sarcoplasmic
Reticulum
Sarcoplasma
sarcomere
plasma
membrane

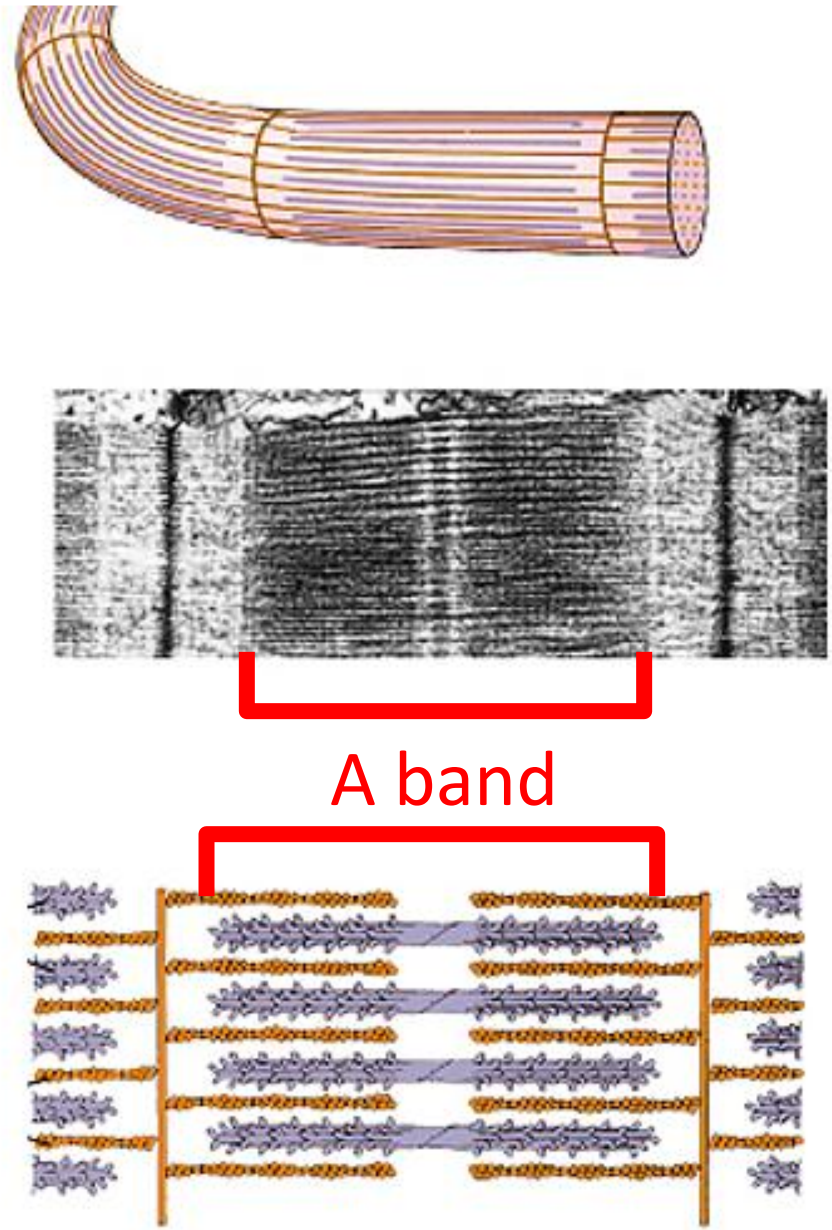


Myofibril

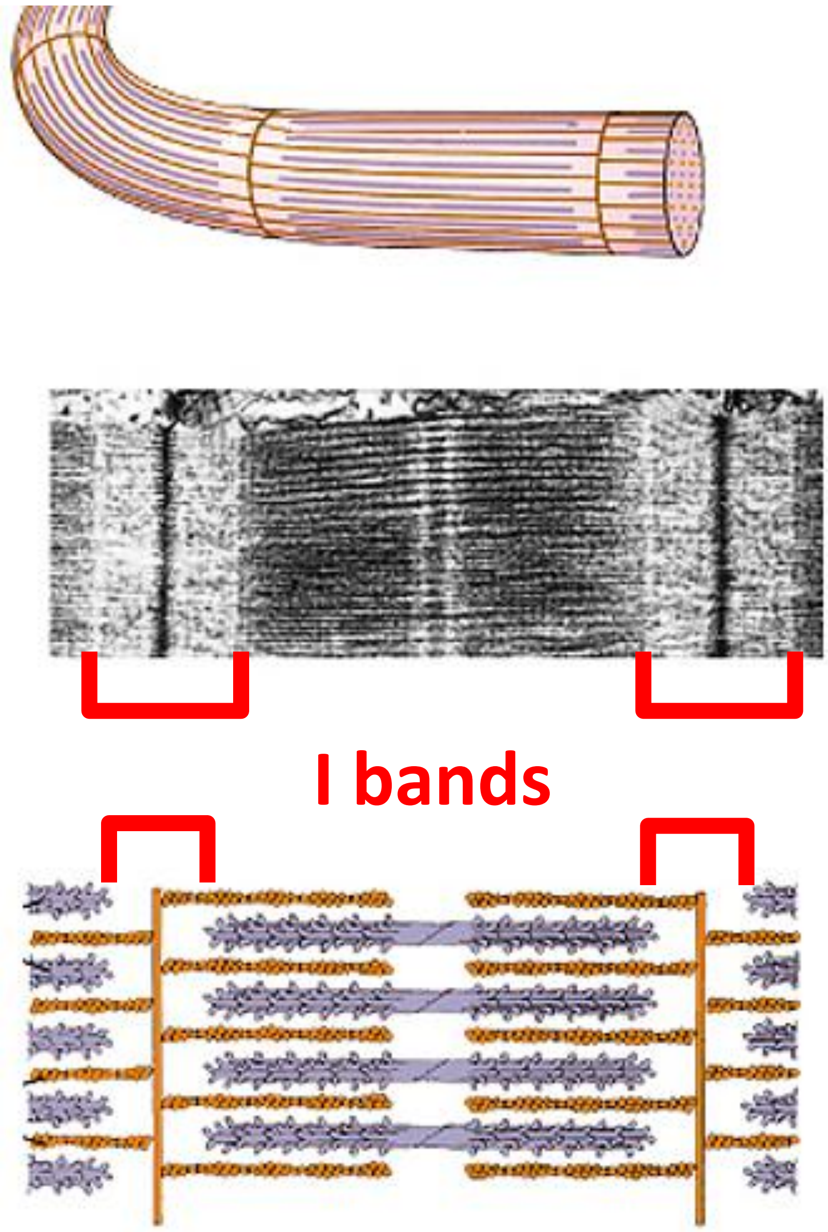
Sarcomere



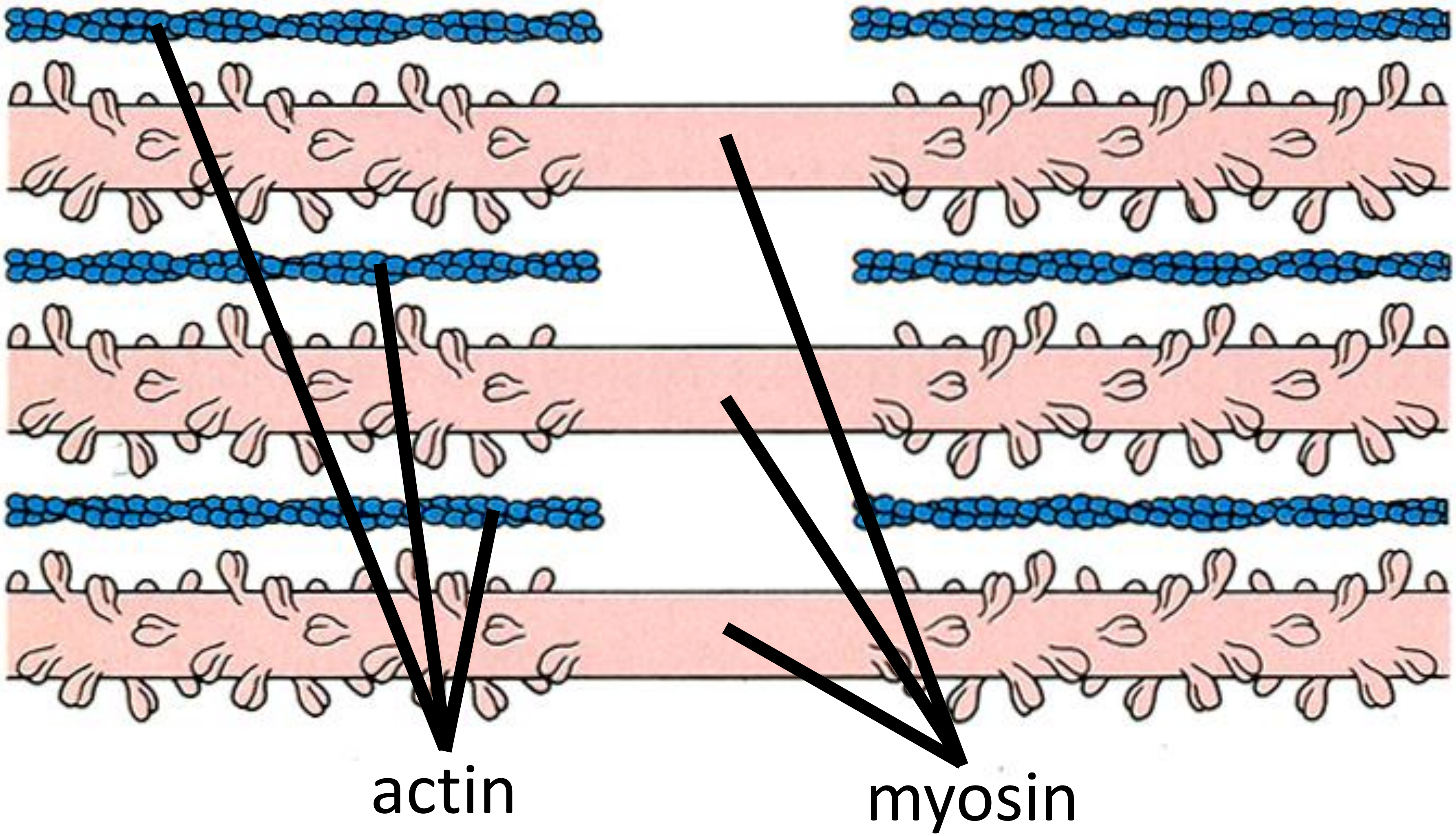
Sarcomere



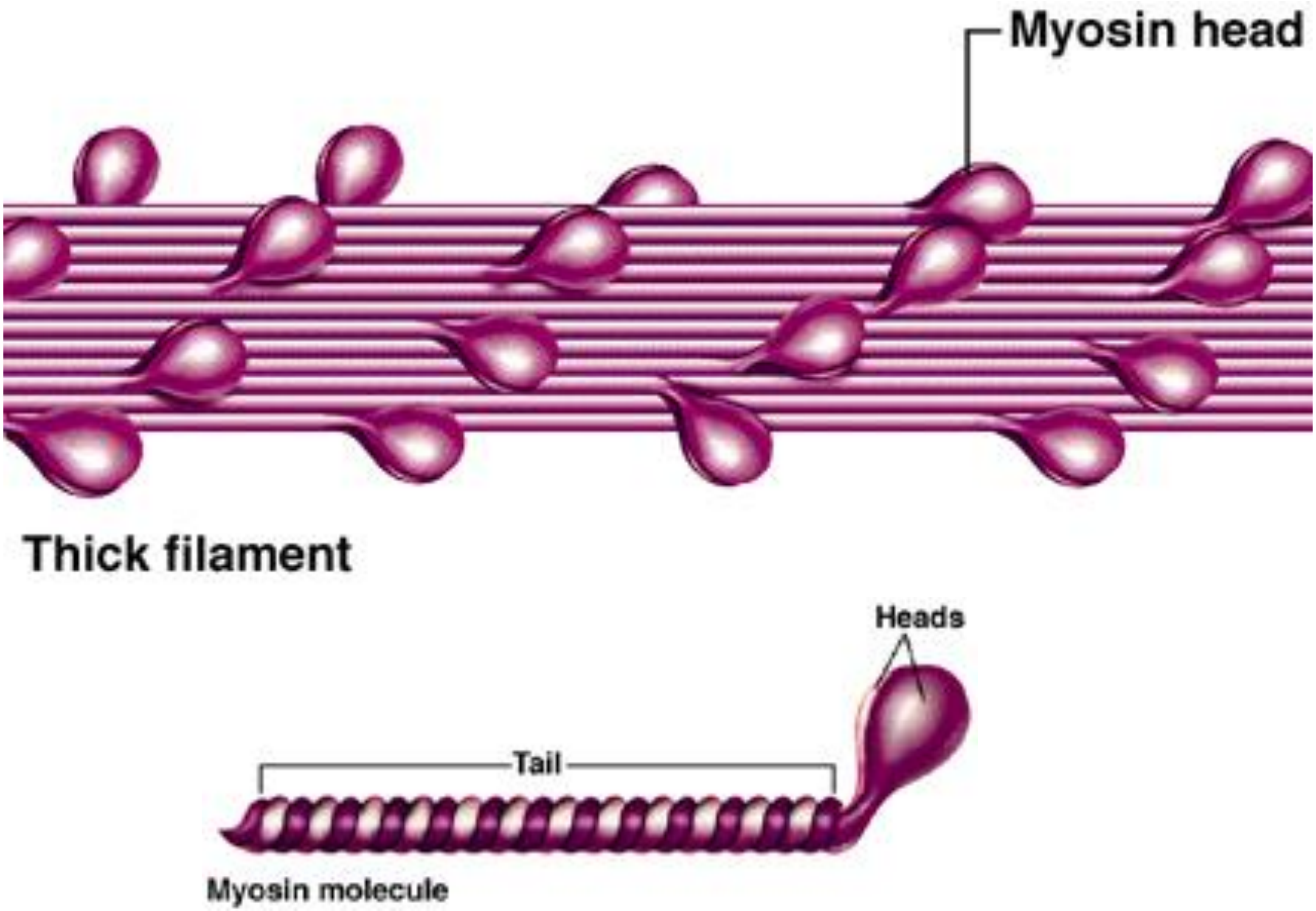
Sarcomere



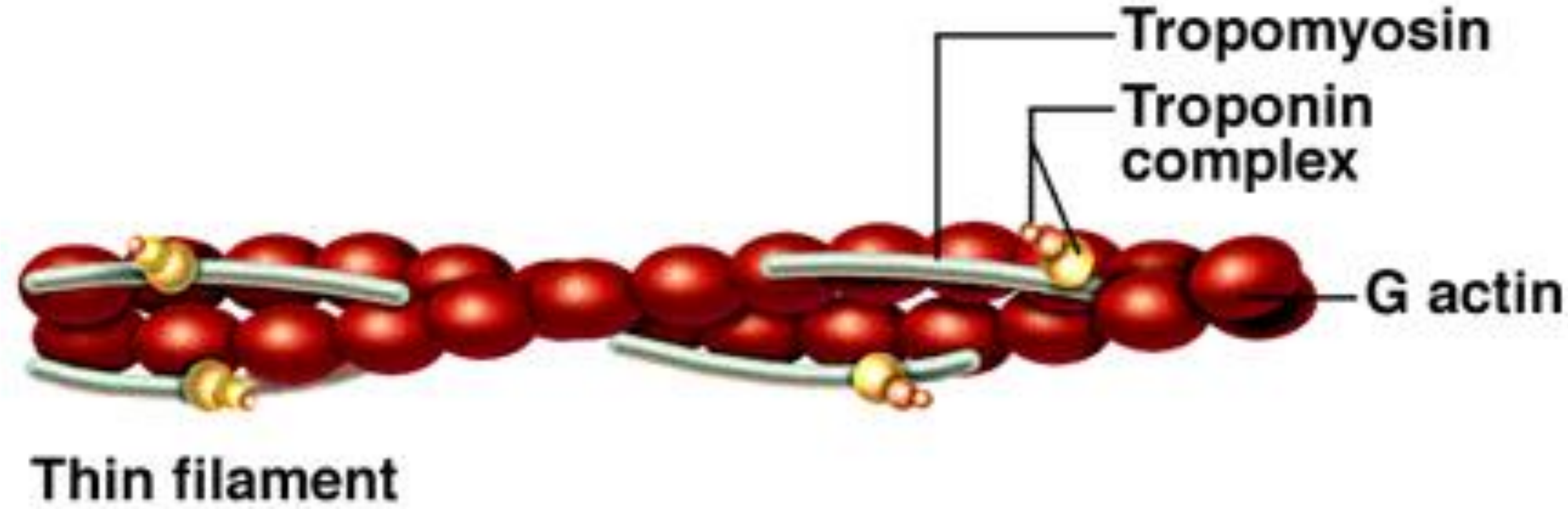
Actin and Myosin Filaments



Myosin (Thick) Filament



Actin (Thin) Filament

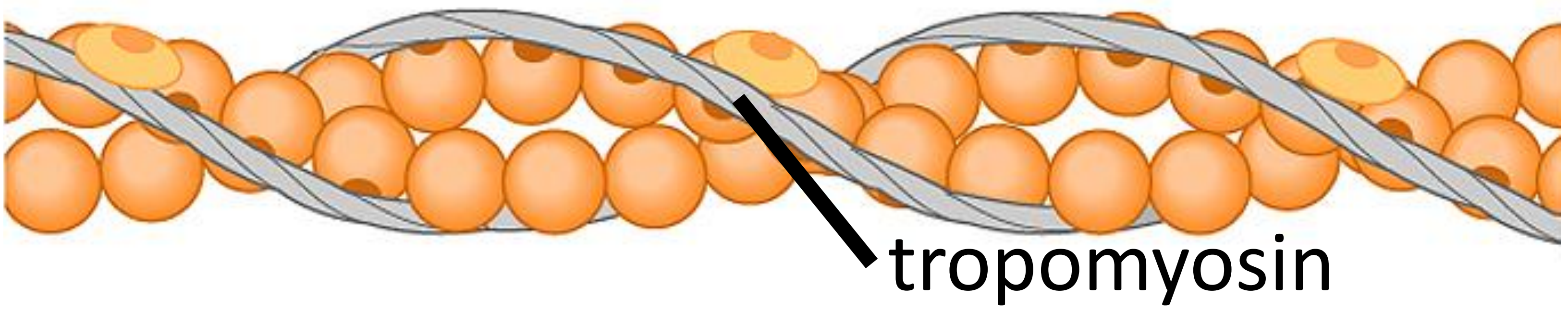


Mechanism of Muscle Contraction

Muscle contraction starts when a nervous impulse sets off a **release of Ca++ from the sarcoplasmic reticulum** to the myofibrils. When the Ca++ concentration increases at the active enzyme site on the myosin filament, **the enzyme ATP-ase get activated**. This ATP-ase splits the ATP found between the actin and myosin filaments, causing a **release of energy**. Most of this energy is used as contractile energy making the **actin filaments slide in between the myosin filaments in a telescopic fashion**, thereby contracting the muscle fibre. When the reaction is reversed (i.e., when the **Ca++ is pumped back,** the contractile ATP-ase activity stops and the filaments are allowed to slip passively past each other), **the muscle is relaxed**

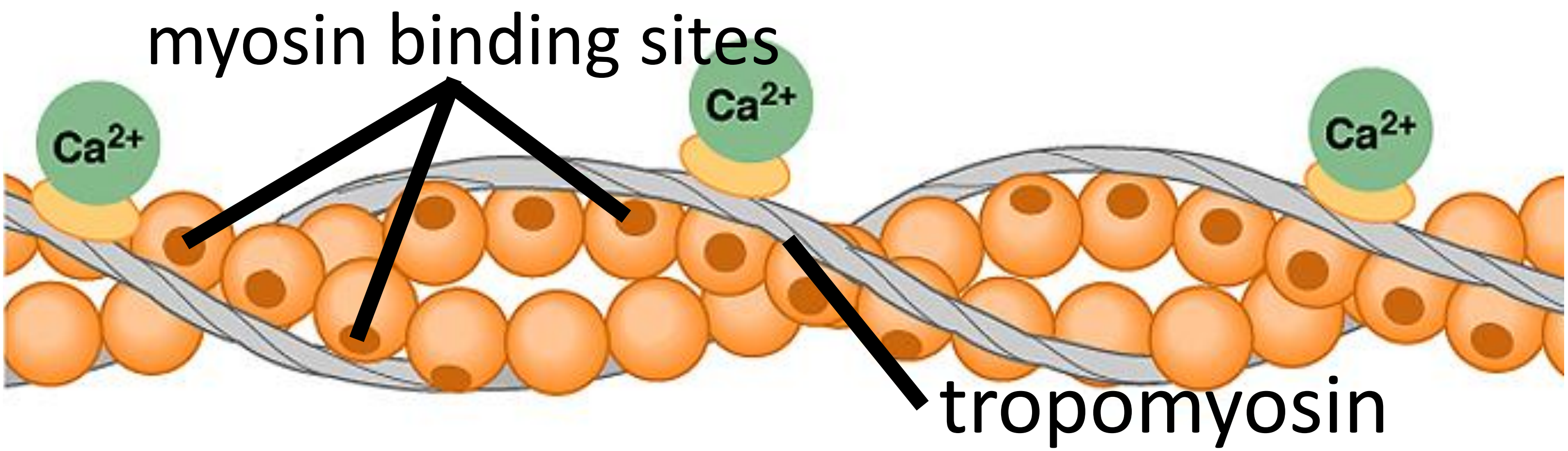
Actin (Thin) Filament

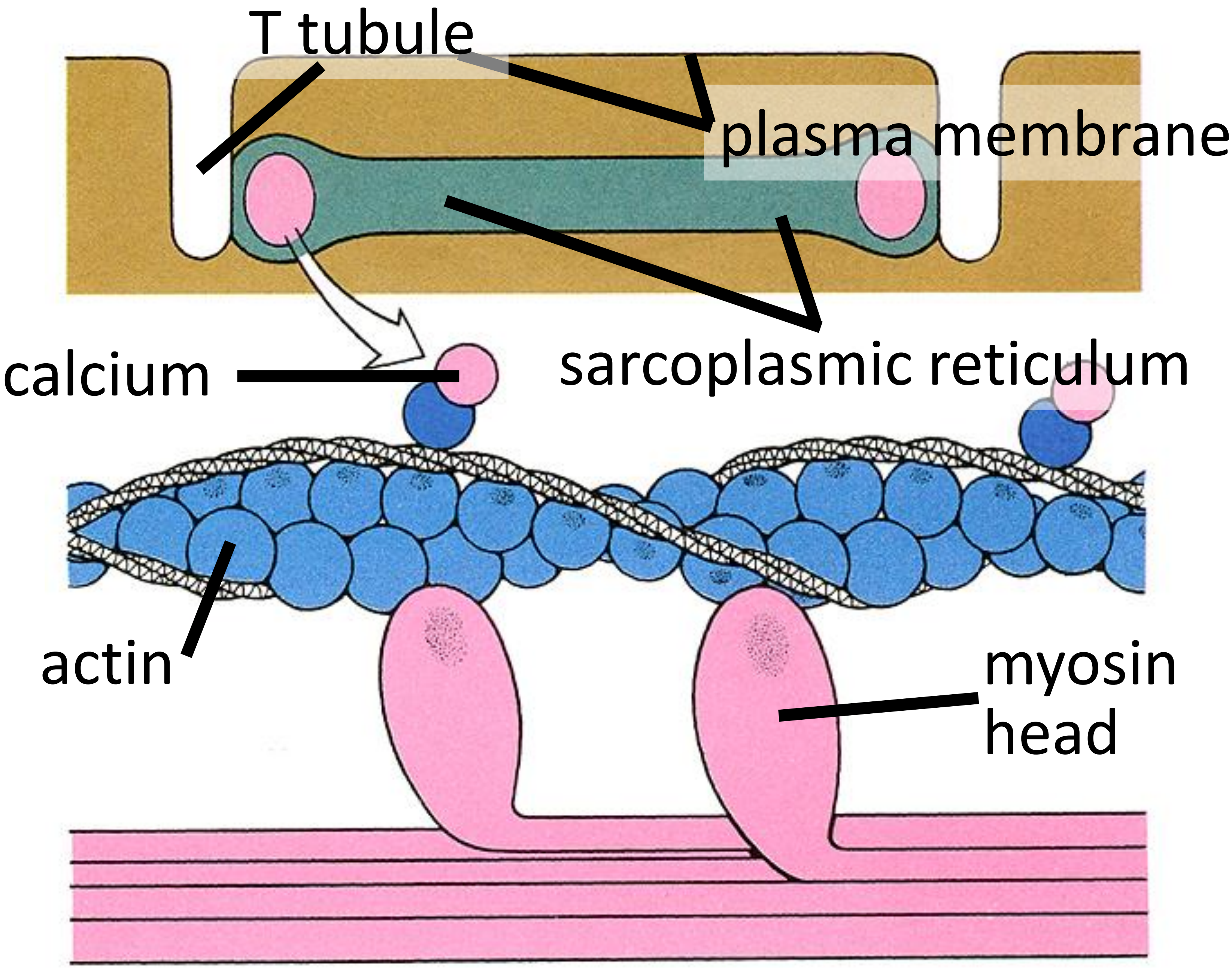
No Calcium Ion



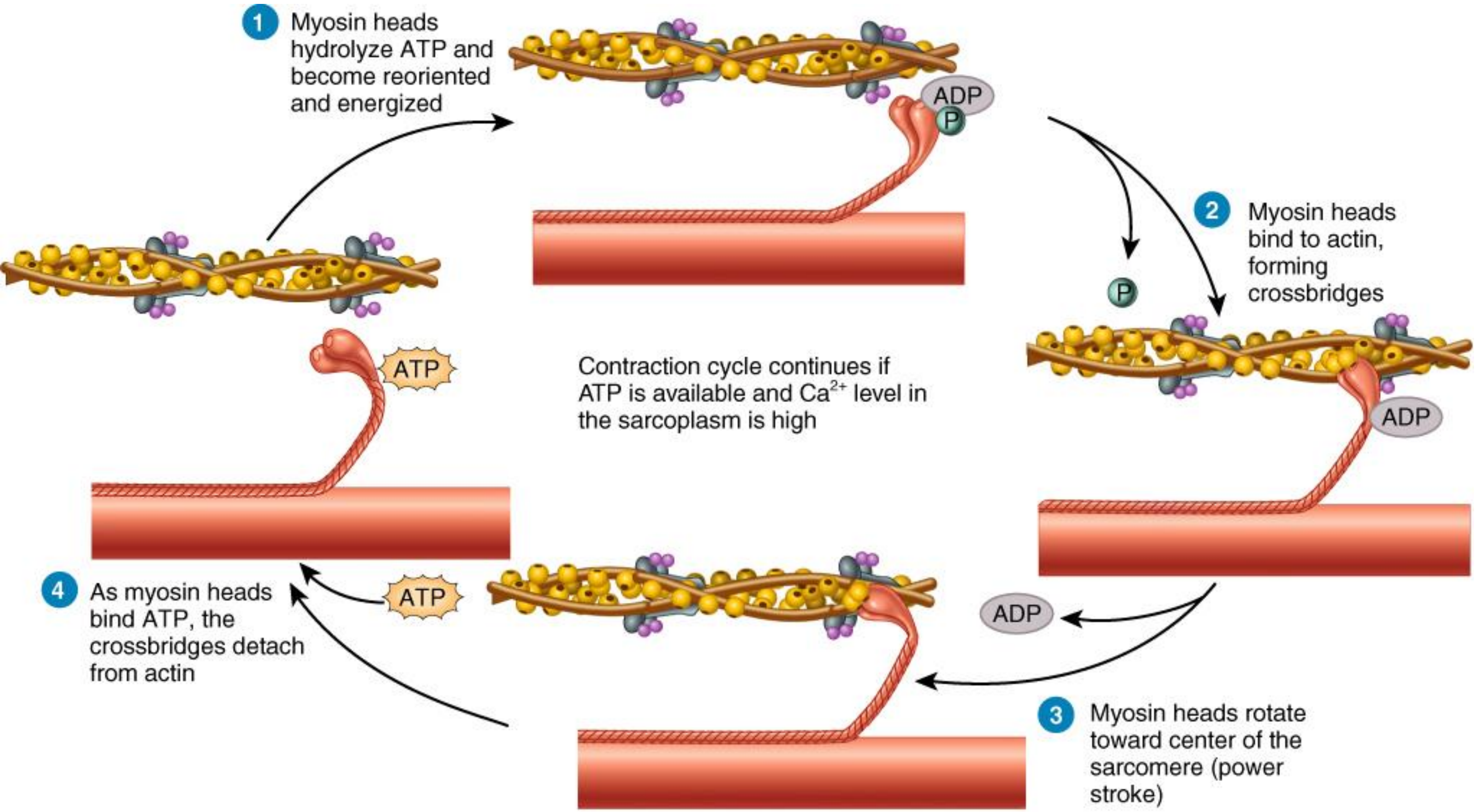
Actin (Thin) Filament

Calcium Ion Present




T tubule
plasma membrane
calcium
sarcoplasmic reticulum
actin
myosin
head

Actin & Myosin Interaction



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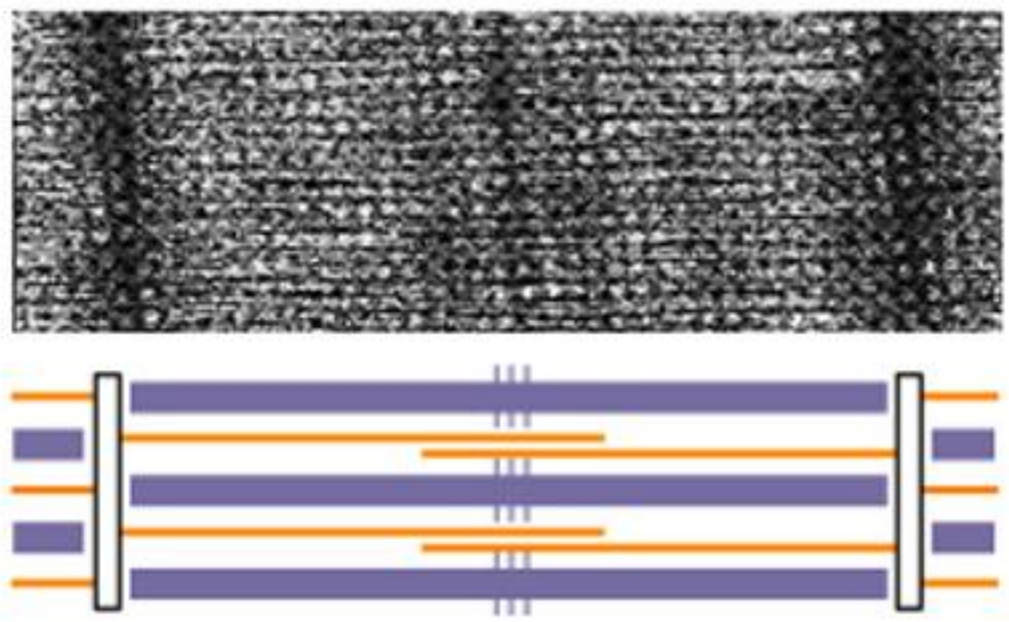
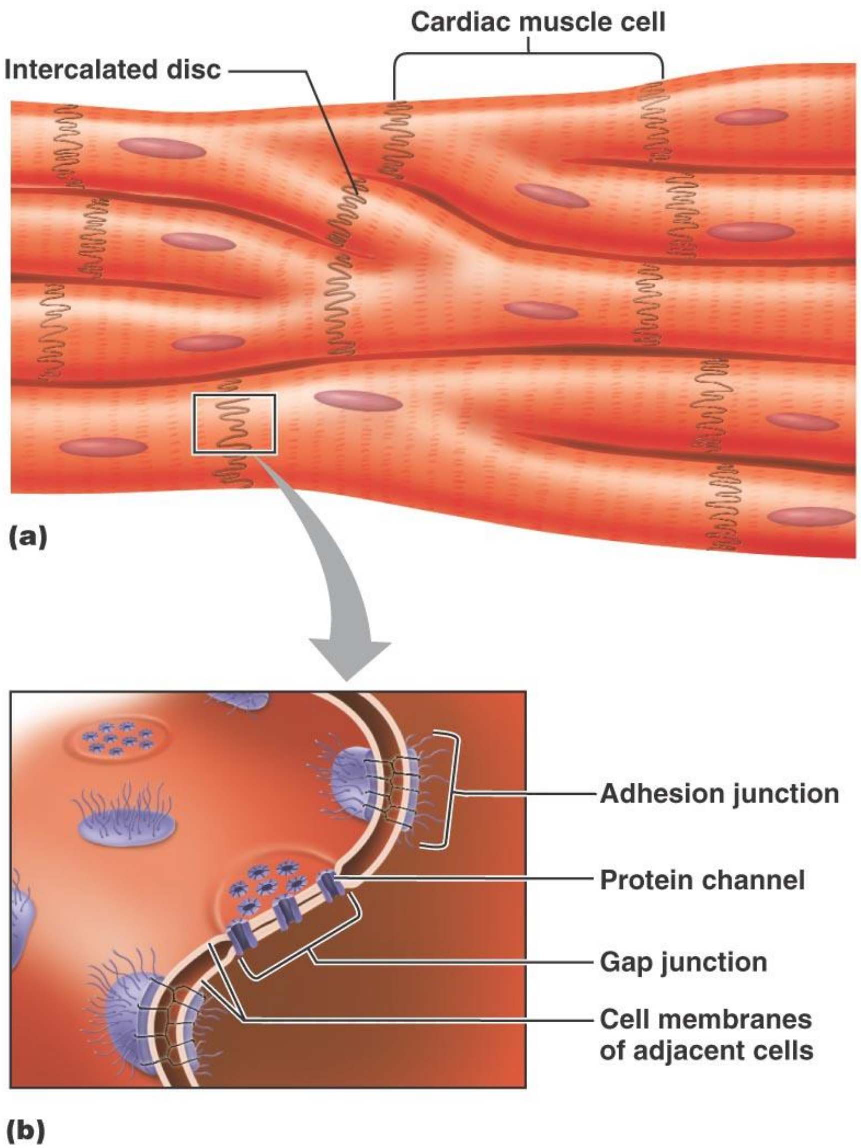
Sliding Filament Hypothesis

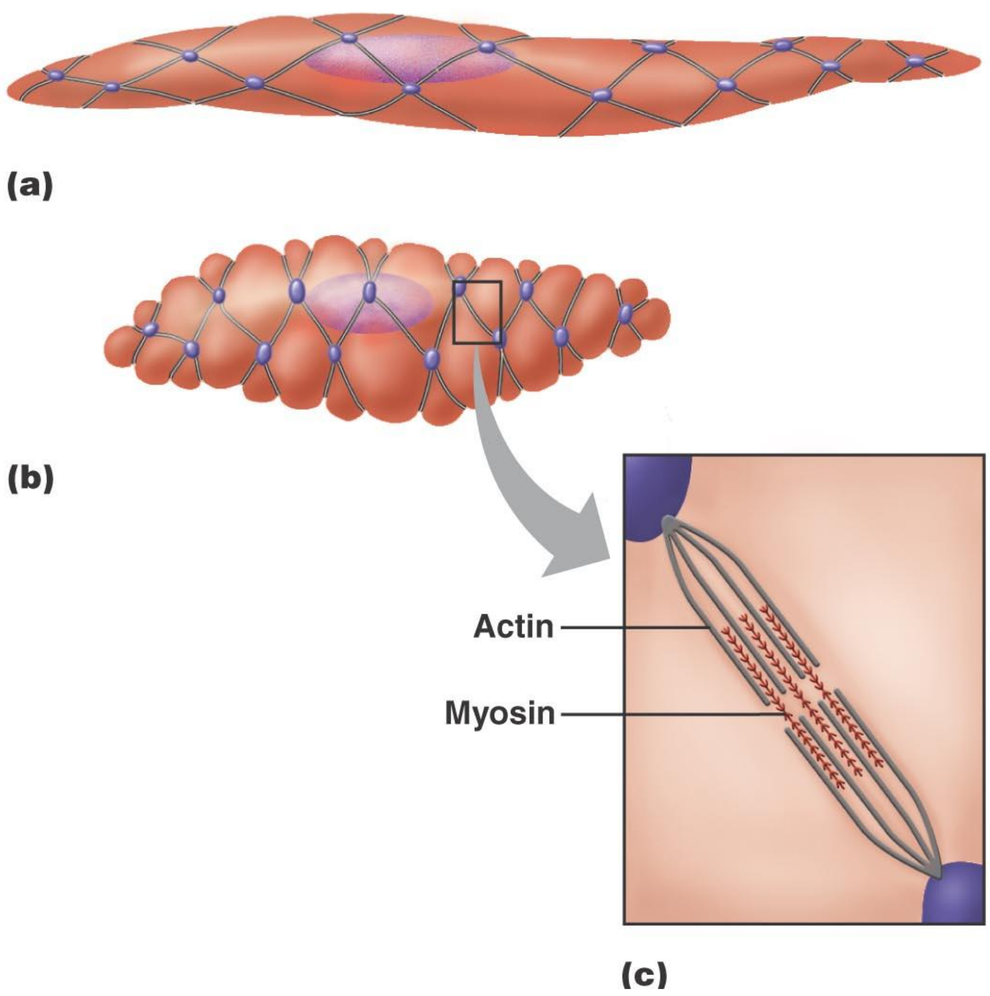


Cardiac Muscle Tissue



Cardiac muscle is involuntary striated muscle found in the walls and histological foundation of the heart. The cells that comprise cardiac muscle called **cardiomyocytes** or myocardiocyteal muscle cells. Coordinated contractions of cardiac muscle cells in the heart propel blood out of the atria and ventricles to the blood vessels of circulatory systems. Cardiac muscle is adapted to be **highly resistant to fatigue**: it has a large number of **mitochondria**, enabling continuous **aerobic respiration** via oxidative-phosphorylation, **numerous myo-globins** (oxygen - storing pigment) and a good supply of oxygen

Smooth Muscle Tissue



Slow responding **non striated involuntary** muscle and they occur in wall of the digestive tract, urinary and gall bladder, ducts and blood vessels. The **slow contraction** and long period of **slow recovery** from inhibition are all typical of smooth muscle. Smooth muscle has only about **half the myosin found in striated muscles**, and lacks their sarcomere organisation [actin : myosin = 7:1 in striated muscle, 15:1 in smooth muscle]. **Troponin is absent** from smooth muscles. **Caldesmon** is a smooth muscle protein that binds reversibly to the actin/tropomyosin filaments and **blocks the actomyosin ATPase activity**

Energy for muscle contraction

The energy source for ATP generation in the light muscle is glycogen, whereas the dark muscle may also use lipids. A major difference is, further, that

The dark muscle contains much more mitochondria than light muscle, thus enabling the dark muscle to operate an extensive aerobic energy metabolism resulting in CO_2 and H_2O as the end products.

The light muscle, mostly generating energy by the anaerobic metabolism, accumulates lactic acid which has to be transported to the liver for further metabolization.

Energy for muscle contraction:

ATP is the only energy source ATP$\rightarrow$(ATPase + H_2O) $\rightarrow$ADP + Pi

ATP is Generated by:

1. creatine phosphate

ADP + creatine phosphate$\rightarrow$creatine + ATP

2. lactic acid fermentation

From stored glycogen via anaerobic glycolysis;

glucose$\rightarrow$pyruvic acid (no O_2) $\rightarrow$lactic acid

3. aerobic respiration

Krebs$\rightarrow$$CO_2$ + H_2O + ATP

Fast glycolitic: white muscle fibers, **anaerobic,** low myoglobin, glycolysis, few mitochondria, fast twitch fibers, **high glycogen** stores, short bursts, fatigues easily

Slow oxidative: red muscle, **aerobic**, high myoglobin, low glycogen stores, **high lipids**, lots of mitochondria, slow, tonic, long distance

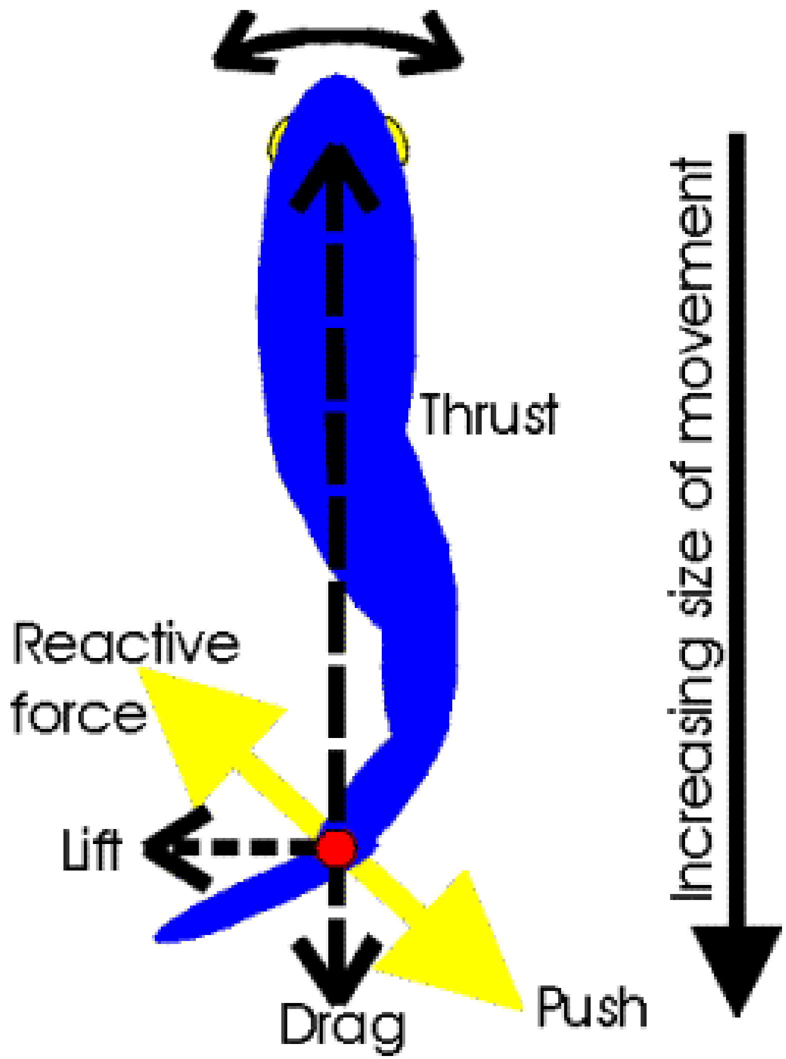
long distance blue fin tuna- mostly red meat
quick bursts- yellow tail- more white meat

The different metabolic patterns found in the two muscle types makes the light muscle excellently fitted for strong, short muscle bursts, whereas the dark muscle is designed for continual, although not so strong muscle movements

Role of Myomere in Swimming

- The **muscles** provide the power for swimming and constitute up to 80% of the fish itself. Muscle blocks are arranged in multiple layers (**myomeres**) arrayed in several directions that allow the fish to move in different directions.
- Fish swim by contracting and relaxing a succession of myomeres (muscle blocks) alternately on each side of the body.
- The alternate shortening and relaxing of successive myomeres bends the body first toward one side and then toward the other, resulting in a series of waves traveling down the fish's body.
- This action starts at the head and progresses down toward the tail.

Diagram showing sinusoidal wave traveling down fish's body



Appendicular Muscles

Appendicular muscles - move fins or limbs

Extrinsic - originate on axial skeleton or fascia or trunk & insert on girdles or limbs

Intrinsic - originate on girdle or proximal skeletal elements of appendage & insert on more distal elements

Fish - Appendicular muscles serve mostly as stabilizers; intrinsic muscles are limited in number

Sound Producing Muscles

- Number of fish make humming, grunting or other low pitched sounds. Such species include toadfish (*Opsanus tau*), squirrel fish (*Holocentrus rufus*) and northern midshipman (*Porichthys notatus*).

- In these fishes striated muscles located symmetrically and completely attached to the wall of swim bladder. Sound is produced by **rapid muscular contractions of the swim bladder** in much the same fashion as sound produce in a stretched taut balloon by dragging a sticky finger across the surface.