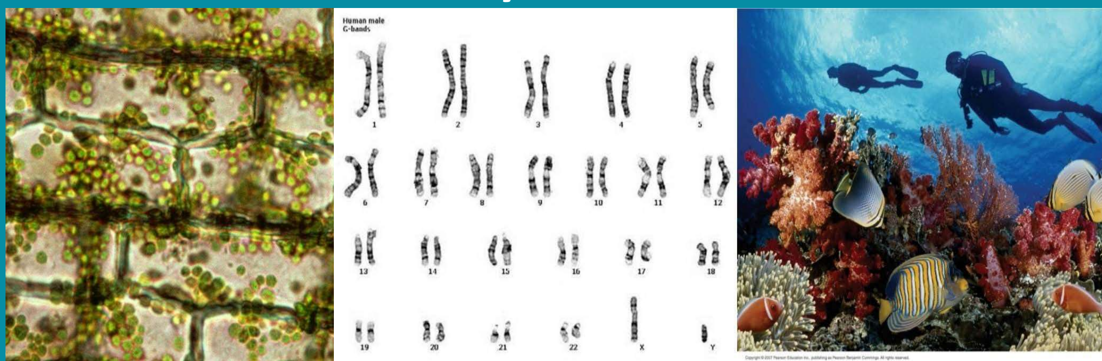
SLE 132 – Form and Function
The Musculoskeletal System



The Musculoskeletal System

Interactions between muscles and skeletons allow movement.

Moving costs energy, so why move?

- To obtain food
- Escaping danger
- Chasing mates

Movement is an important feature of animals

Animals move in many different ways including:

•Running, walking, hopping, crawling

•Flying, slithering, swimming

•Gliding over a surface with the aid of slime *e.g. snails and slugs*

- Different modes of locomotion vary in efficiency

Different modes of locomotion vary in efficiency

Heavier animals are actually more efficient

Due to:

- More efficient/powerful muscle structures
- Metabolic power is found to be proportional to body mass.
- Momentum

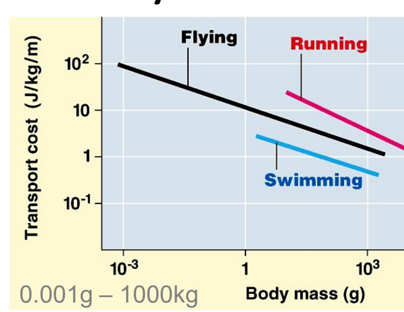
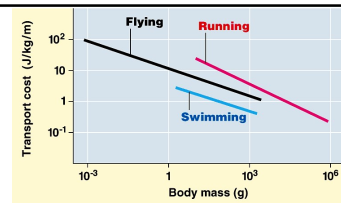


Fig 49.25

Flying costs the most energy
Running second most.
Swimming least

In order to move have to overcome two forces:

•FRICTION/DRAG
•GRAVITY



What are the advantages and disadvantages of each type of locomotion?

- ***SWIMMING:***
- **RUNNING/ WALKING:**
- **FLYING:**

Think of an example of an adaptation to overcome the disadvantages of each type of locomotion.

Locomotion

To move, animals must exert a force against their environment

They need:

- Force generating tissue **(muscle)**
- Supporting tissue to provide leverage **(skeleton)**

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Roles of skeletons

- Support the body, maintaining shape and preventing collapse.
- Protect soft tissue *eg. Skull, ribs in Humans*
  Exoskeleton of Crayfish
- Provide a structure for muscle attachment.
- Offer a structure against which the muscles can work.

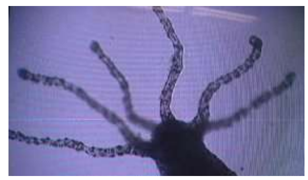
There are 3 types of skeletons

1. **Hydrostatic skeletons** – Fluid under pressure
2. **Exoskeletons** – External covering
3. **Endoskeletons** - Internal framework

Hydrostatic Skeletons

Fluid under pressure:

- fluid is held under pressure in a closed body compartment.
- movement is due to muscles contracting & pushing against the fluid filled compartment.
- Example Cnidarian *Hydra*:
  - Hydra moves by closing mouth & using contractile cells in wall of gastrovascular cavity (filled with water)



Hydrostatic skeleton in the earthworm

- The earthworm has its whole length is broken up into small coelomic compartments (segmentation).
- The muscles in each compartment can contract or relax separately

2 sets of muscles.

Circular muscles: narrow & elongate body, pushing segments forwards.

Longitudinal muscles: shorten body, pulling trailing segments forwards.

Cheatae anchor the segments to the soil to prevent backsliding

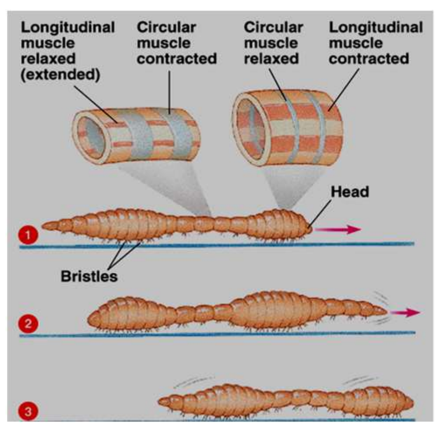


Fig. 49.28

- Hydrostatic skeletons work well for aquatic animals & animals which burrow.
- most animals with hydrostatic skeletons are soft and flexible.
- Other forms of terrestrial locomotion require other forms of skeleton:
  - » Exoskeleton
  - » Endoskeleton

Exoskeleton

- Skeleton on the outside surface
  - – eg: scallops (not really skeleton), grasshoppers, crayfish
- Provides protection, support and an advanced locomotion
- Muscles are attached to jointed exoskeleton for movement

Exoskeletons

Problem with exoskeletons- how to grow larger?

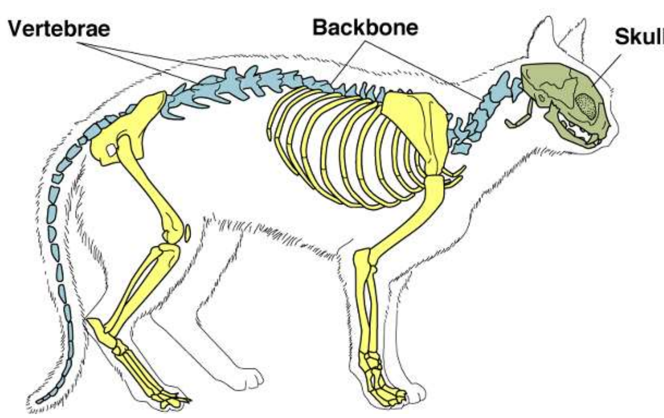
– Molluscs have hard shell, as animal grows shell has extra added to outer edge e.g.: mussels, scallops, snails

– Arthropods need to periodically shed exoskeleton (moult) as they grow and a new, larger exoskeleton produced e.g.: crayfish

https://www.youtube.com/watch?v=lQyopA3JoWo (2:36 min)

Endoskeleton

- The skeleton is located inside the animal -in amongst the soft tissues
- Is derived from mesoderm
- e.g.: echinoderms, vertebrates

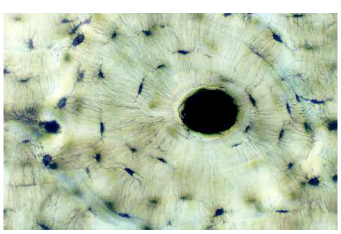


Endoskeleton in Echinoderms

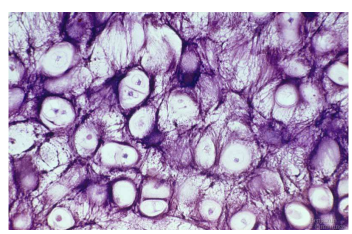
- Calcium carbonate spicules laid down beneath skin 
  - formed within cells
  - spicules may be like plates and join together to form a rigid skeleton
- spines articulate with skeleton

Most vertebrate skeletons are made of two types of connective tissue:

1. Bone



2. Cartilage



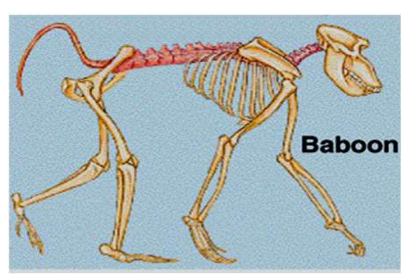
- Cartilage is located at the ends of bones, where flexibility is needed *eg: joints, rib cage humans*
- Exception for vertebrates is the sharks and rays – their skeleton is cartilage only - *chondrichthyes*

Bone

- matrix is harder due to calcium salts & less water
- Cells are osteocytes & are in lacunae
- collagen fibres are present
- stronger than cartilage but breaks more easily
- blood supply is through bone in canals

Humans have distinctive skeletal features –
many associated with bipedal locomotion

- Large skull to encase large brain, located on top of backbone
- Backbone S-shaped -helps balance
- Pelvic girdle oriented vertically
- Hands specialised for gripping & manipulation -freed from locomotion
- Feet for supporting whole body



Modifications for flight: bird bone structure & wing:

- Bones are honeycomb (many pockets of air) – reduces weight
- Frigate bird – wingspan of >2m.
  - Skeleton weighs only 113g.

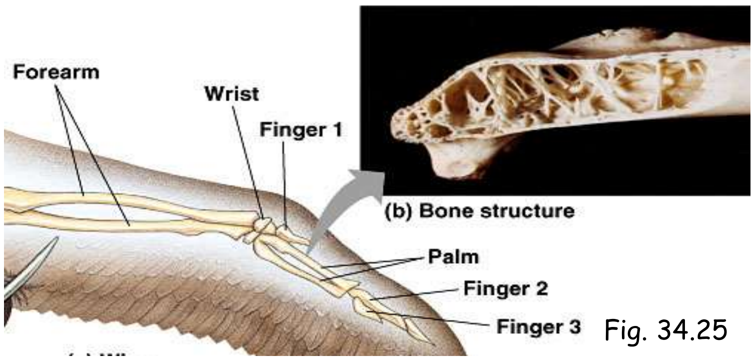


Fig. 34.25

Quick Question

1. Bone is a type of ________.

A) connective tissue

B) epithelial tissue

C) extracellular matrix

D) adipose tissue

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Quick Question

2. An endoskeleton is the primary body support for the ________.

A) insects, including beetles

B) bivalves, including clams

C) cartilaginous fishes, including sharks

D) annelids, including earthworms

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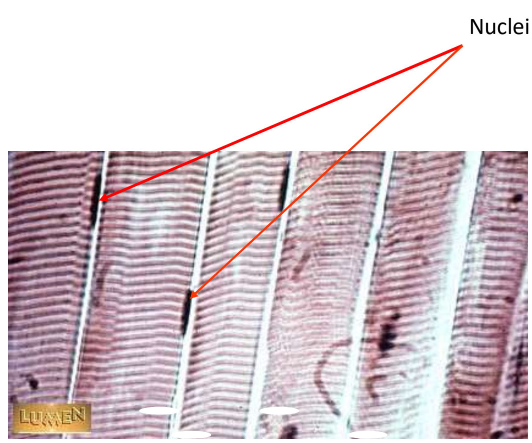
3 different muscle types

Skeletal muscle

- found in both invertebrates & vertebrates
- attached to skeleton by tendons
- responsible for movement of the skeleton
- voluntary in vertebrates-can be moved at will
- striated in appearance (pattern of stripes)



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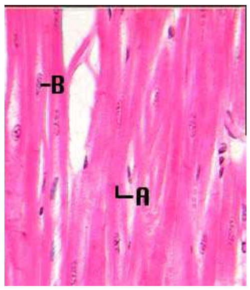
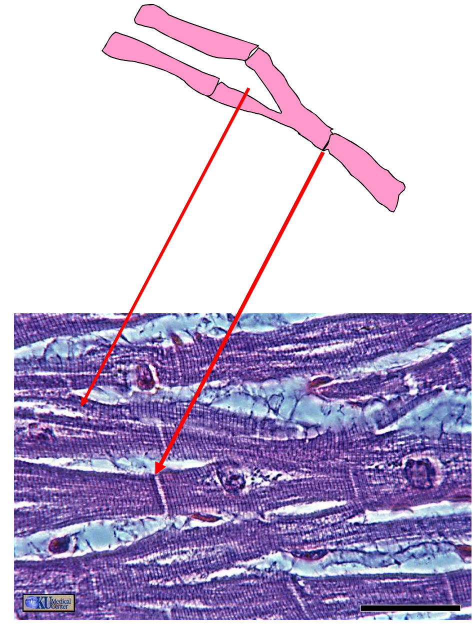
Cardiac muscle

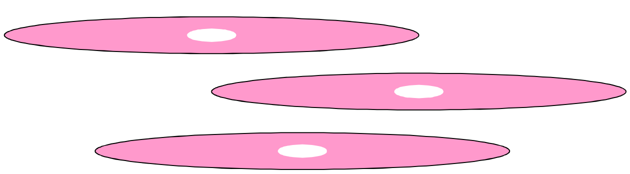
- Only found in the vertebrate heart
- also striated, but branched
- intercalated discs
  - specialised junctions between cells
  - enable tight electrical connection

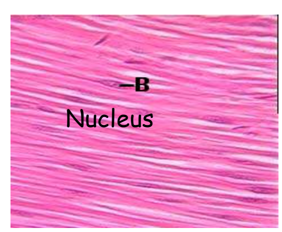




Smooth muscle

- Found in both invertebrates & vertebrates
- Around internal organs such as the gut, blood vessels
- No striations
- Involuntary
- Slower contractions than skeletal, but can sustain the contractions for long periods





The skeleton and muscles interact for movement

- Muscles are attached to skeletons by tendons ...
  which are fibrous connective tissue
- Muscles can only actively contract (or shorten)
- To be elongated (or extended), muscles must be pulled by another muscle
- Thus, you need antagonistic muscles for movement
  (Skeletal muscles work in opposite pairs)

Example 1: Human Endoskeleton

- The human arm has antagonistic muscles for movement.
- *Biceps* and *Triceps*.
- Note: muscles actively contract, but elongate only when passively stretched.

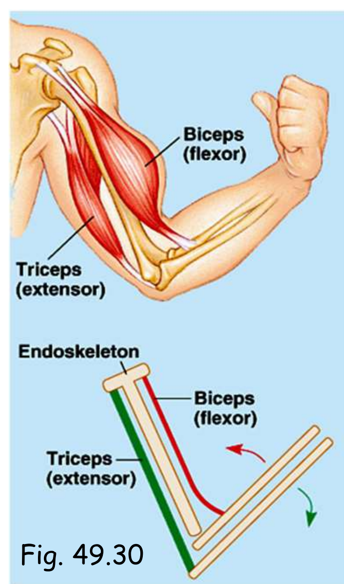


Fig. 49.30

Example 2:
Exoskeleton of an Insect

- Muscles attached to inner surfaces of exoskeleton
- At joints exoskeleton is thin & flexible
- antagonistic muscles

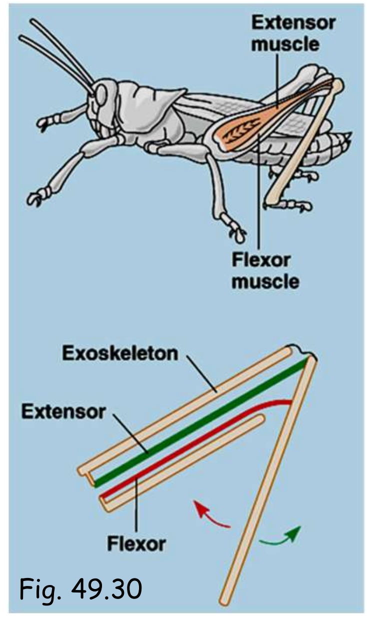


Fig. 49.30

The structure of vertebrate skeletal muscle

Skeletal muscle is made up of

- bundles of parallel **muscle fibres**
- each fibre is a single cell with many nuclei and contains a bundle of **myofibrils**
- a myofibril consists of repeating units called **sarcomeres**
- the region between 2 dark narrow lines called **Z lines** in the myofibril

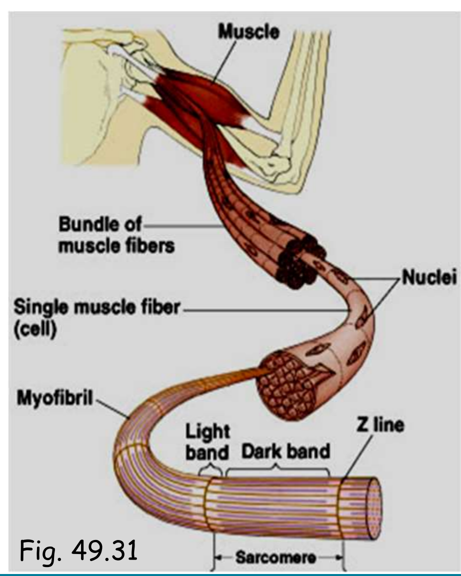
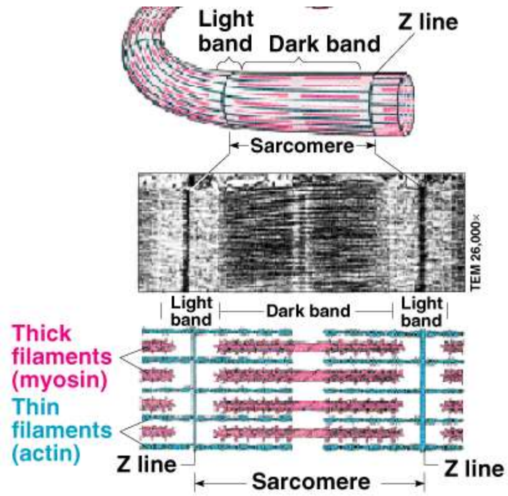


Fig. 49.31

The structure of vertebrate skeletal muscle

Fig. 49.31

- The myofibril is comprised of filaments of protein
  - **thin filaments** of **actin** and regulatory proteins
  - **thick filaments** – **myosin** molecules
- Interactions between myosin and actin underlie muscle contractions
- Sarcomeres are the functional unit of the muscle



How does muscle contract?

Contraction occurs by the filaments sliding over one another.

- Sarcomeres shorten when the thin actin filaments slide across the thick myosin filaments towards the center of the sarcomere.
- The length of the filaments stays the same.

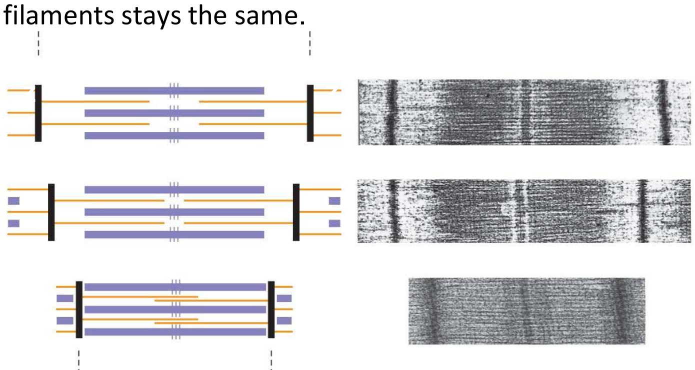


Fig 50.27

Mechanisms of sliding filaments

1. The head of a **myosin** molecule is bound to actin.
2. The bond is broken when **ATP** binds to myosin
3. ATP is broken down into **ADP and P**, and position of myosin head changes & binds to a new actin site, further along molecule (called a cross-bridge)
4. Release of ADP and P from the myosin bends the myosin head and the molecules slide over one another **(power stroke)**

- The cross-bridge is broken when a new ATP binds to the myosin head (1)
- The process repeats in cycles

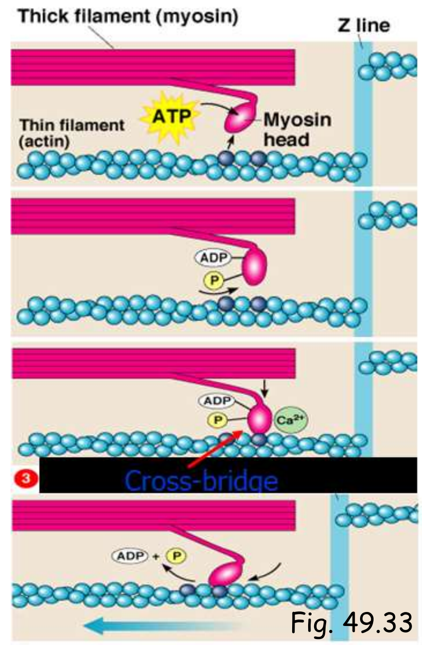


Fig. 49.33

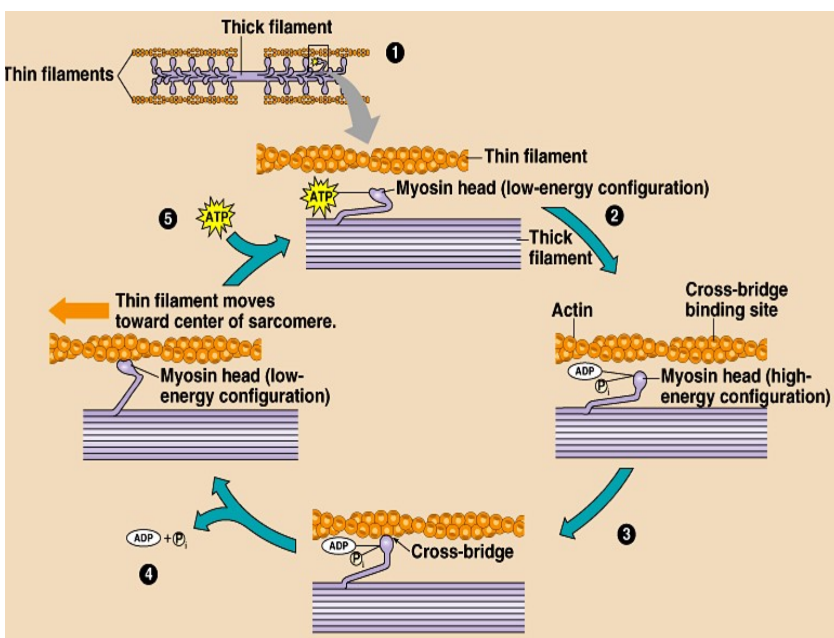


Fig. 49.33

Control of muscle contraction

- **Ca^{2+} ions and regulatory proteins control muscle contraction**
- In muscle at rest myosin binding sites on actin are blocked by regulatory proteins
- When Ca^{2+} ions released, they bind with regulatory protein Troponin & binding sites are exposed
- Muscle cell is now able to contract

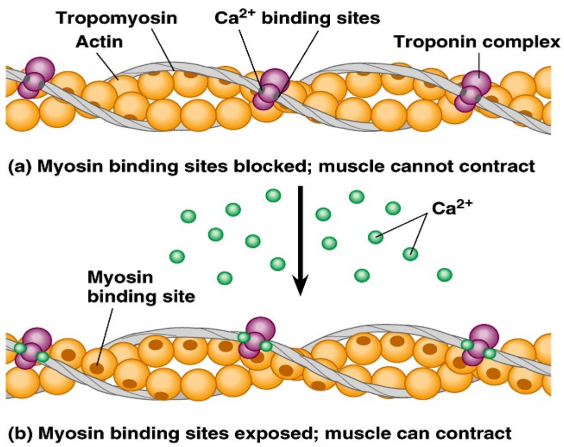


Fig. 49.34

Stimulating a muscle contraction

- Muscles are stimulated to contract by nerves
- An nerve impulse comes from a motor neuron cell to the neuromuscular junction
- A neurotransmitter, **Acetylcholine**, is released stimulating the muscle cell
- The stimulus changes the permeability of the **sarcoplasmic reticulum** (specialised endoplasmic reticulum in muscle cells)

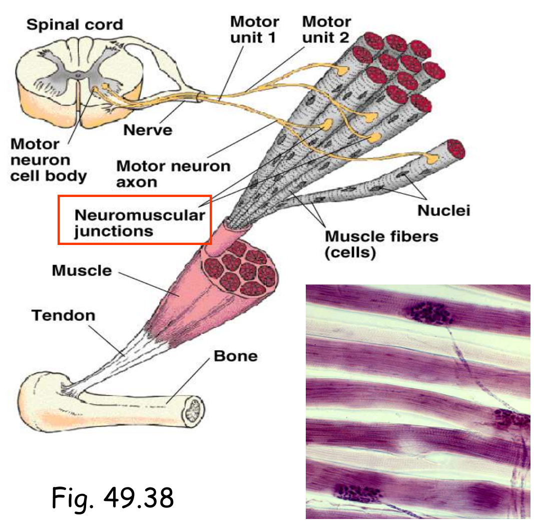


Fig. 49.38

Stimulating a muscle contraction

- The sarcoplasmic reticulum (SR) **stores Ca^{2+} ions**
- the change in permeability in the SR causes the **release of Ca^{2+}** into the cytoplasm of muscle cells
- The Ca^{2+} ions bind to regulatory protein and **myosin binding sites become exposed**

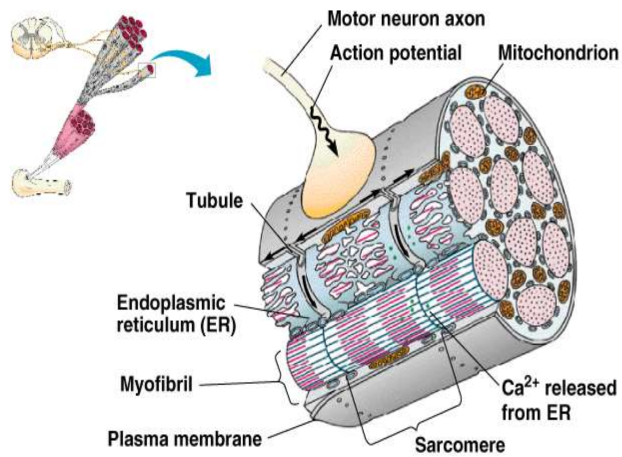


Fig. 49.35

How muscle action is varied

- A **motor unit** consists of a single motor nerve cell & all the muscle fibres it controls
- When a motor nerve cell fires, <u>all fibres in unit contract</u>
- The strength of muscle action depends on how many motor units are activated
  - *eg: to lift a fork/ lift a textbook*

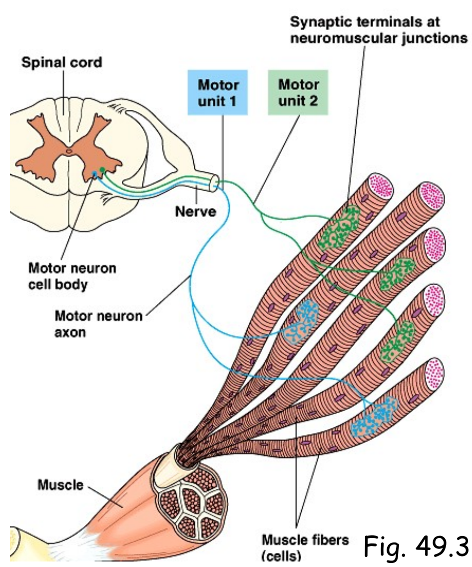


Fig. 49.38

Another way of obtaining variation in contractions

- Variation in frequency of nerve impulses in the motor nerve cells (neurons) can vary strength of muscle response
- If a second impulse (action potential) arrives before response to first is complete -> **summation** occurs & a greater muscle contraction

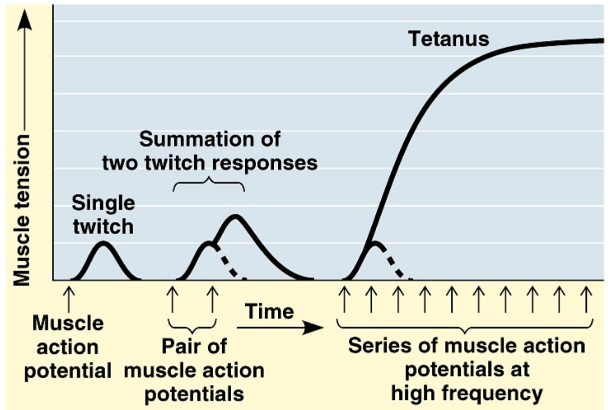


Fig. 49.37

Putting it all together: what is the sequence of events in muscle contraction? Start from the action potential reaching the synaptic terminal of a motor neuron.

Quick Question

1. Muscles are connected to bones by ________.

A) thick filaments

B) ligaments

C) tendons

D) myofibrils

Quick Question

2. Functionally, what is the muscle fiber's fundamental unit of contraction?

A) thick filament

B) thin filament

C) myofibril

D) sarcomere

Quick Question

3. According to the sliding-filament model of muscle contraction, a sarcomere contracts when its ________.

A) thick filaments slide across the ends of the sarcomere

B) thin filaments slide across the ends of the sarcomere

C) thin and thick filaments slide further away from each other

D) thin and thick filaments slide past each other to get closer together