

Human Anatomy & Physiology – Muscular System



Learning Outcomes

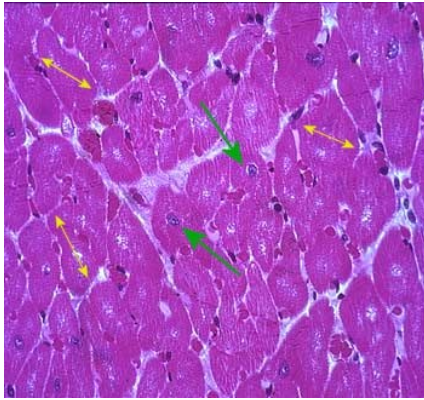
- To describe the different types of muscle
- To know the striated muscle structure on a microscopic and macroscopic
- To understand how the neurological components link with the mechanical and chemical components to produce movement

Muscle Types

- Three types of Muscle
 - Skeletal
 - Cardiac (myocardium)
 - Smooth
- key differences - appearance, structure, innervation, fuel supply.

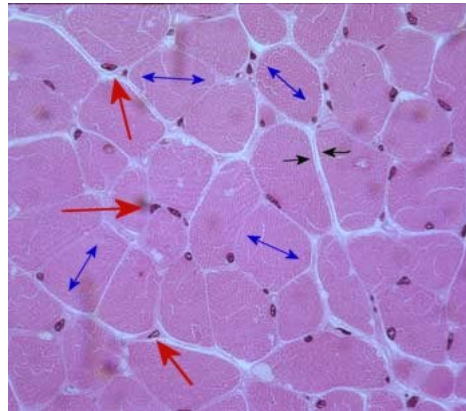
Cardiac muscle	Involuntary controlled by autonomic nervous system
Smooth muscle	
Skeletal muscle (aka striped or striated muscle)	voluntary controlled by somatic nervous system

Cardiac muscle



Central nuclei and intercalated discs

Skeletal muscle

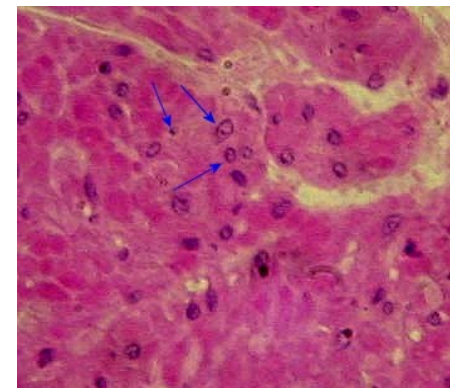


Peripheral nuclei

<http://uk.youtube.com/watch?v=PJDrR3sZPZU&feature=related>

Smooth Muscle

Irregular spaced and sized nuclei



Muscle Function

- Produce movement
- Maintain postures and positions
- Stabilise joints
 - Usually for other muscle activity
- Support and protect viscera
- Control cavity pressures
- Produce heat to maintain body temperature
- Control entrance and exits to body
 - swallowing, defecation, urination, blood flow
- Energy Storage

Physiological Nature of Muscle tissue

- Excitability– the ability to respond to a stimulus
- Contractility – the ability to contract and create a tension
- Extensibility – the ability to be stretched
- Elasticity – the ability to resume its resting length after it has been stretched or contracted.

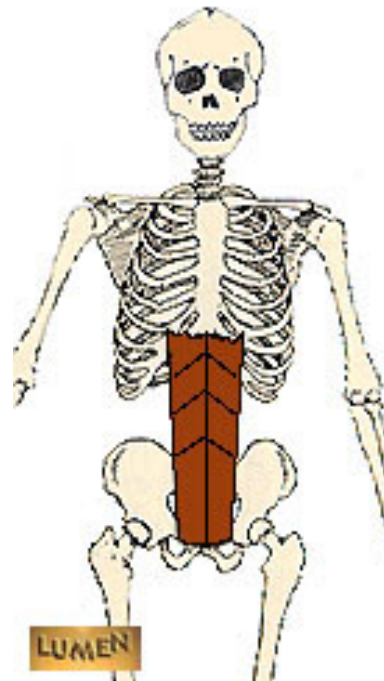
Gross Skeletal Muscle Structure

- The arrangement of muscle fibre is dependent upon the line of action of pull required. As such muscle fibres can be arranged as;
 1. Longitudinal
 2. Fusiform or spindles
 3. Penniform
 4. Bipenniform
 5. Triangular or fan shaped
 6. Multipenniform
 7. Rhomboidal and Rectangular

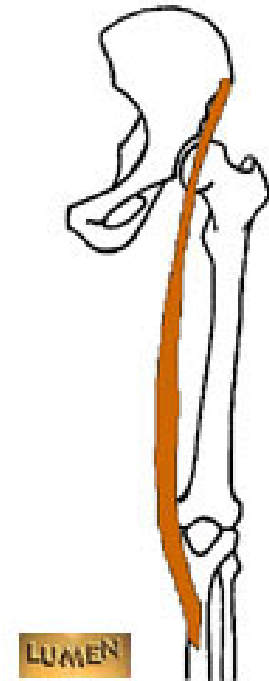
Longitudinal

- Long strap like muscle whose fibres lie parallel to its long axis e.g. rectus abdominus and sartorius.

Rectus abdominus



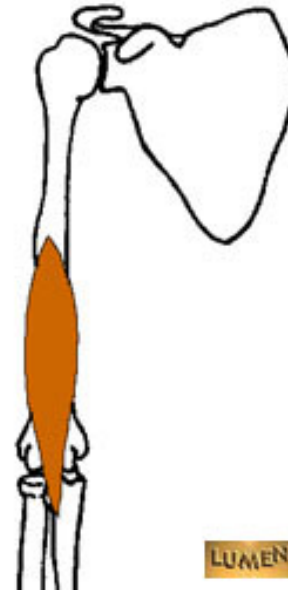
sartorius



Fusiform or spindles

- A rounded muscle whose fibres taper at either end. It may be long or short e.g. brachialis and brachioradialis

Brachialis



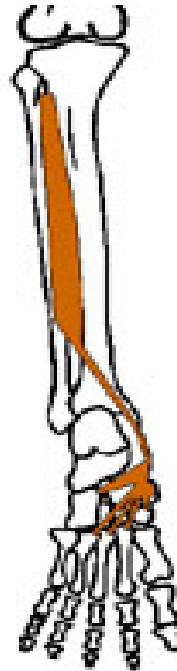
Brachioradialis



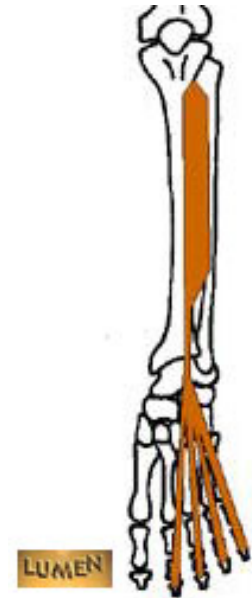
Penniform

- Fibres are short, parallel and featherlike extending diagonally along the side of a tendon e.g. extensor digitorum longus and tibialis posterior.

Tibialis posterior



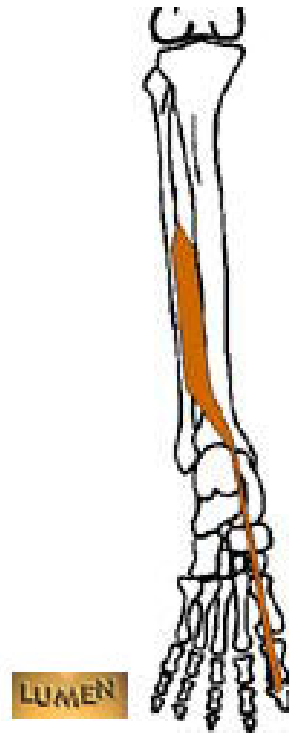
Extensor digitorum longus



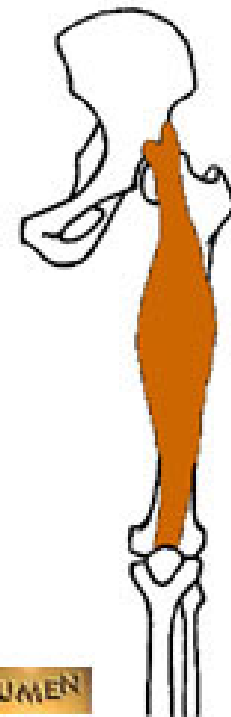
Bipenniform

- A double penniform arrangement with fibres extending in pairs either side of the tendon a long central tendon e.g. flexor hallicus longus and rectus femoris

Flexor hallicus longus

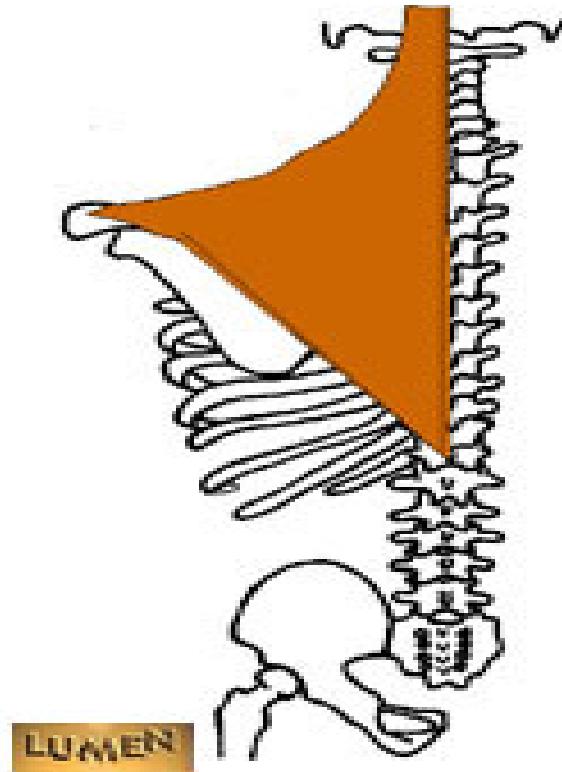


Rectus femoris



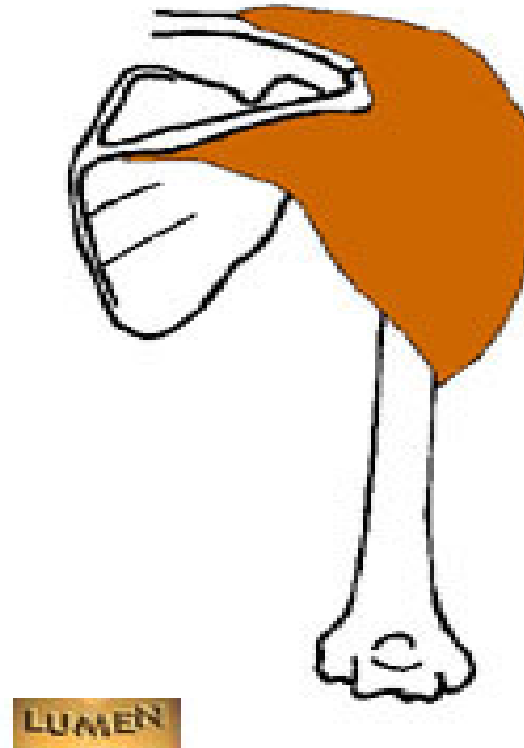
Triangular or convergent shaped

- Combined arrangement of flat and fusiform muscles, has a broad origin and its fascicles converge toward a single tendon of insertion
- E.g. Pectoralis major and Trapezius



Multipenniform

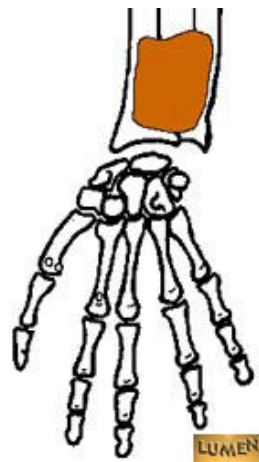
- Several tendons are present muscle fibres running with diagonally between them e.g. deltoid
 - medial
 - anterior
 - posterior



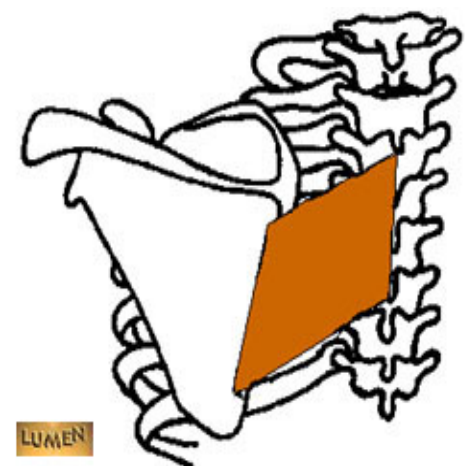
Rhomboidal and Rectangular

- Muscles are four sided and usually flat with the fibres are parallel e.g. pronator quadratus and rhomboid.

Pronator quadratus

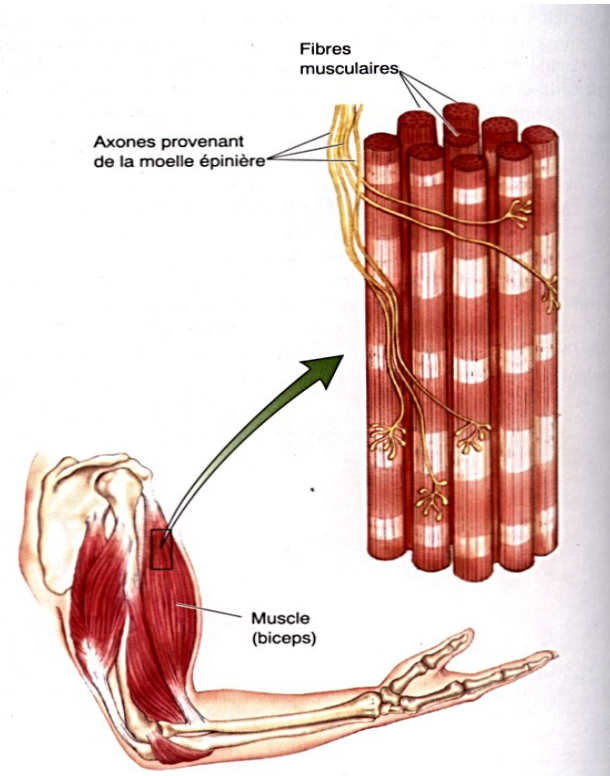


Rhomboid Major

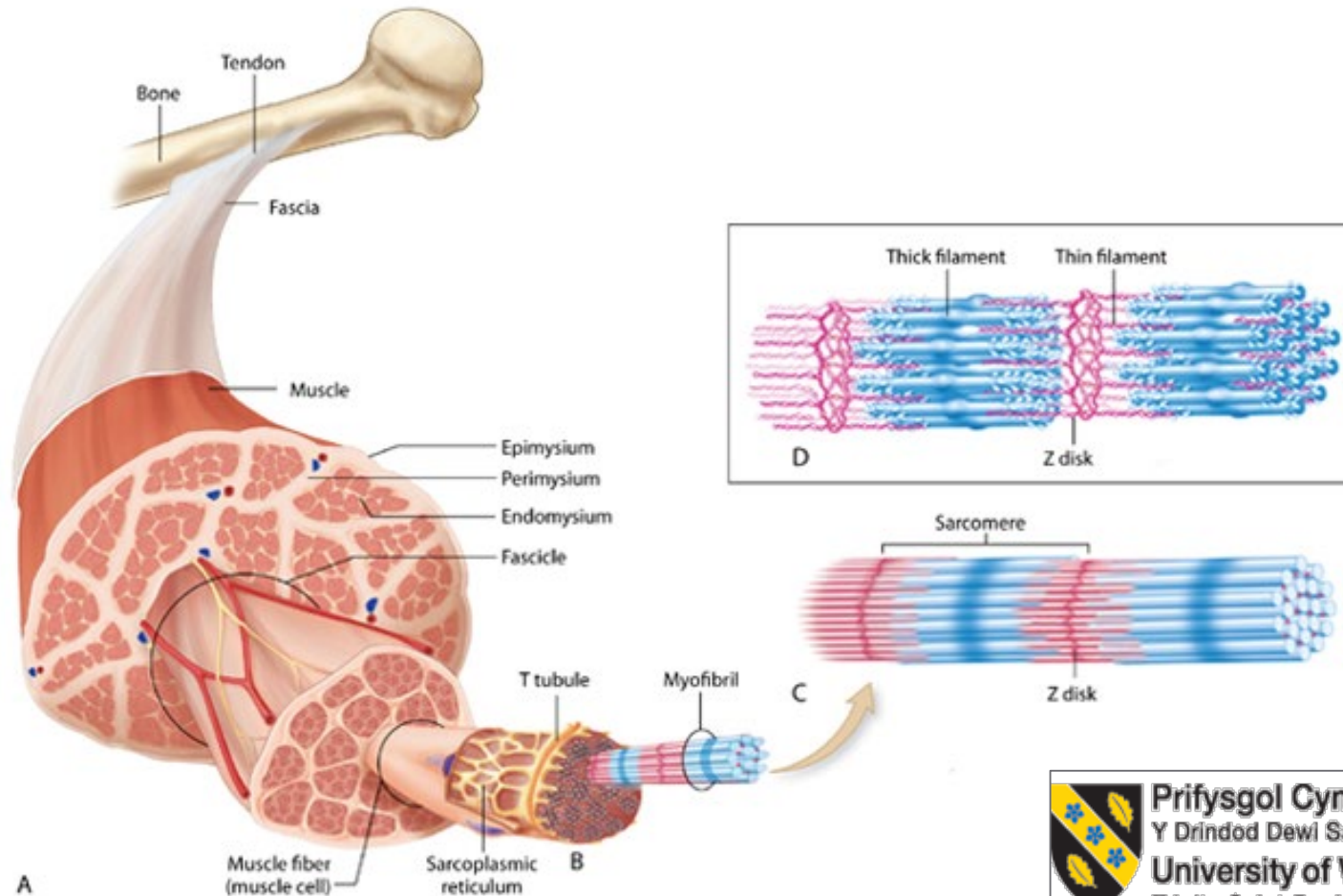


Muscle Fibres

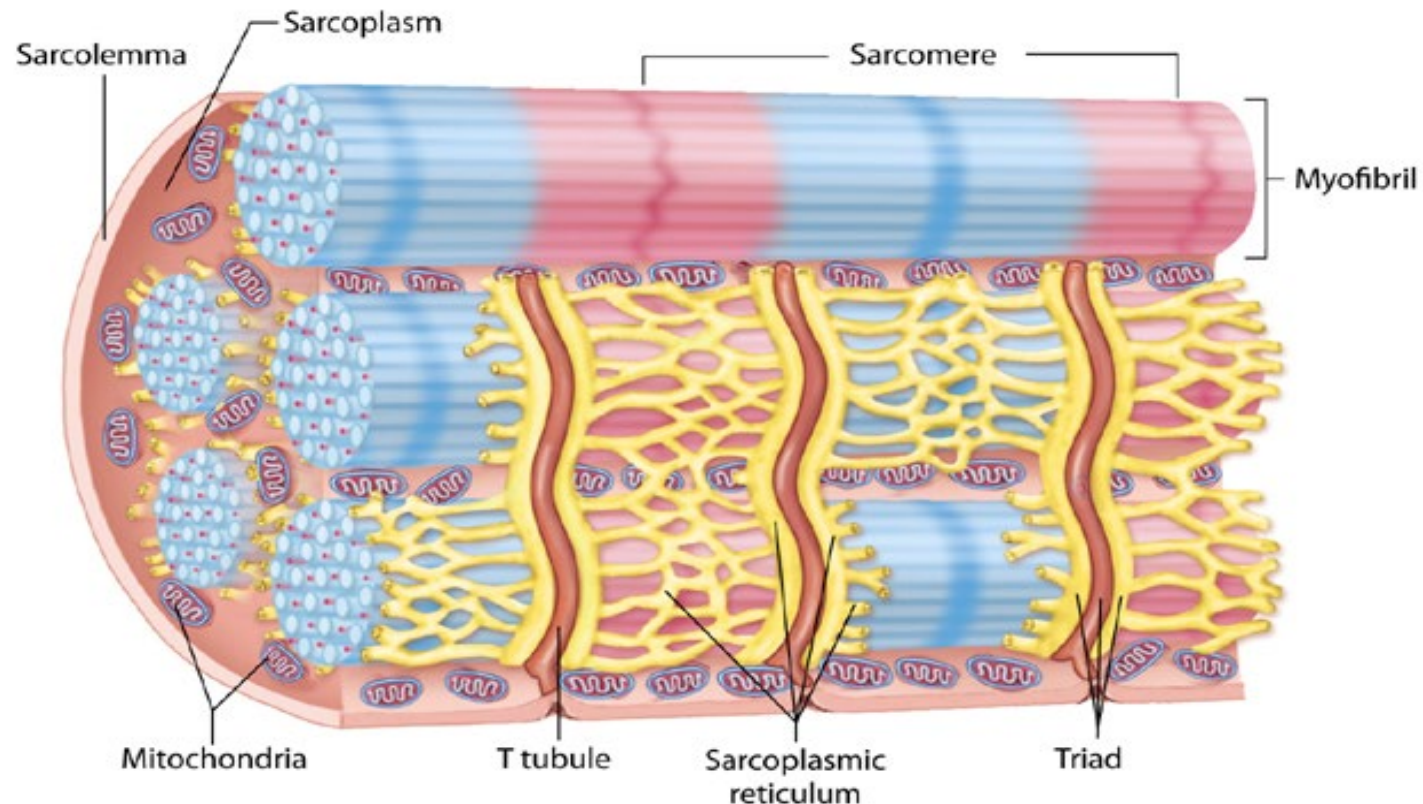
- **Muscles** are composed of fibres
- **Fibres** are composed of myofibrils which are arranged in parallel (side by side)
- **Myofibrils** are composed of sarcomeres in series (end to end)
- **Sarcomeres** are the functional unit of the muscle cell and are composed of thick (myosin) and thin (actin) myofilaments



Organizational Hierarchy



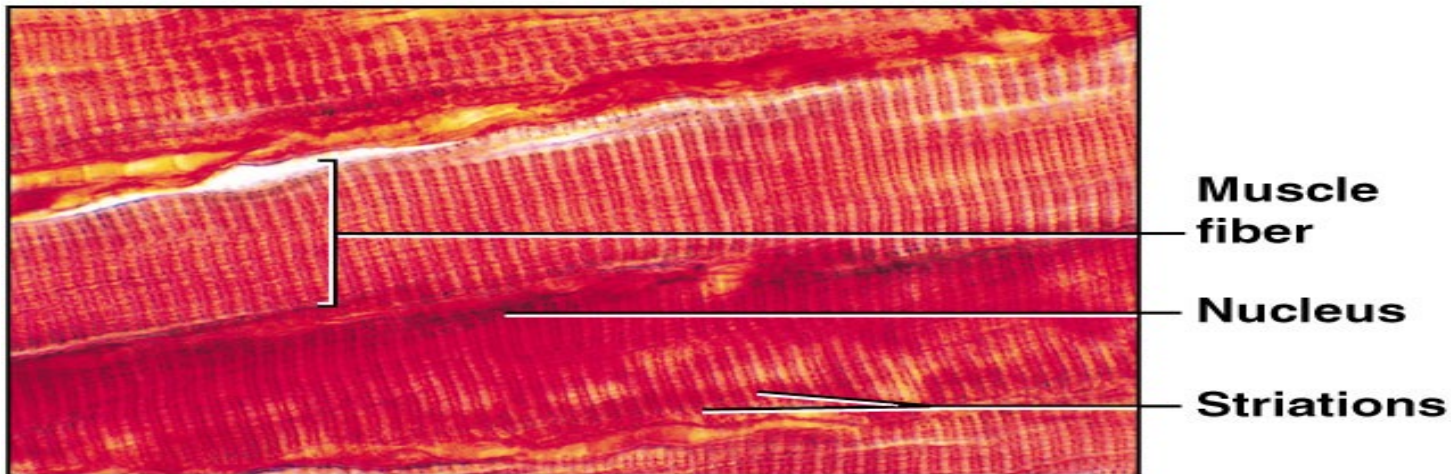
Components of the Muscle Cell/ Tissue



Muscle Cells

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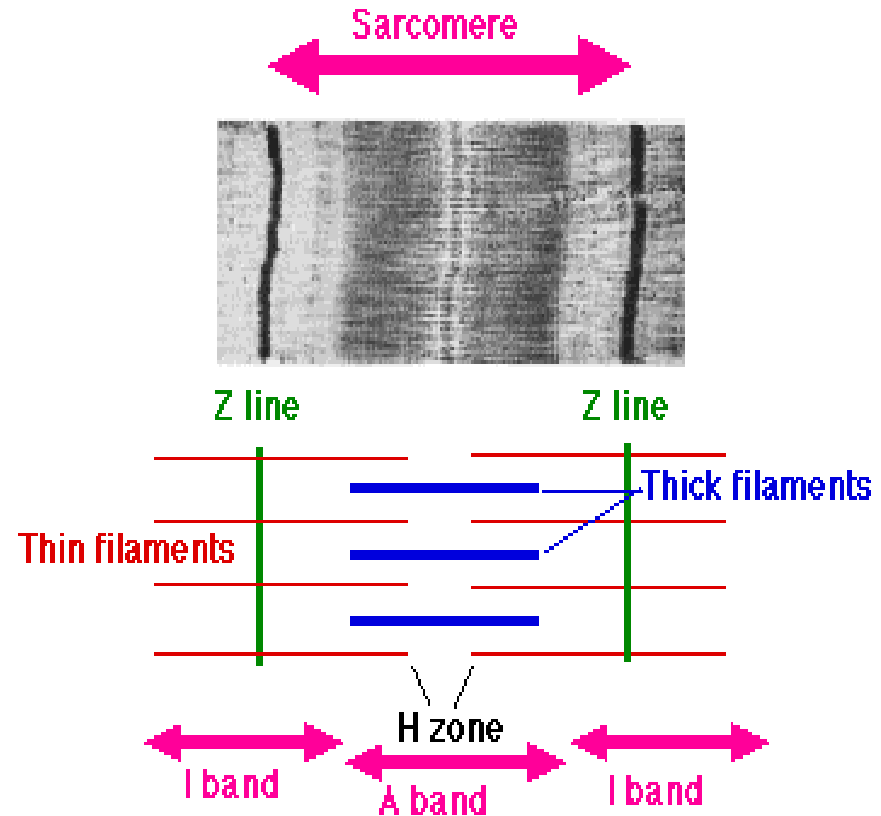
Human skeletal muscle



Each of these striations (light area to light area) is a sarcomere.

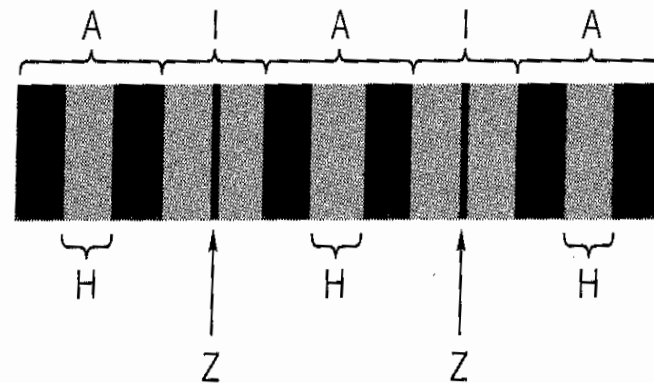
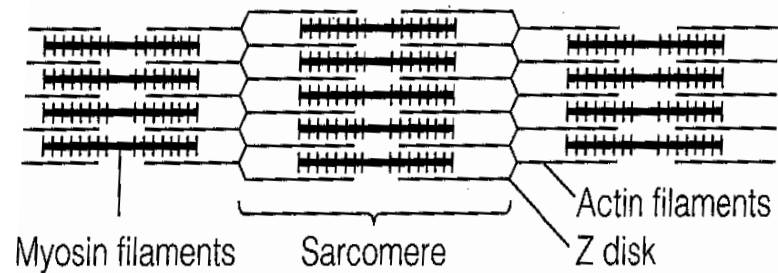
Sarcomere

- A-band
 - mid-portion of the sarcomere
 - appears dark,
- I band
 - at ends of sarcomere
 - light



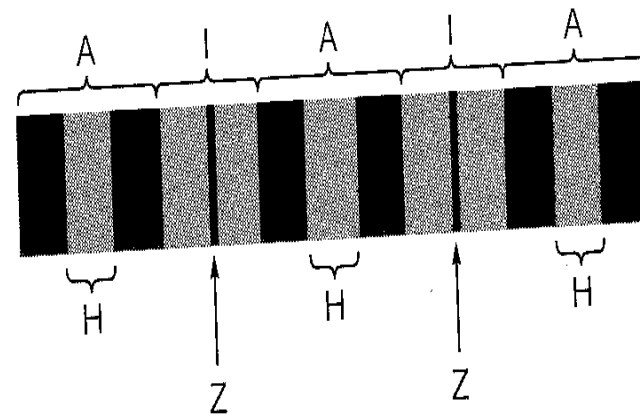
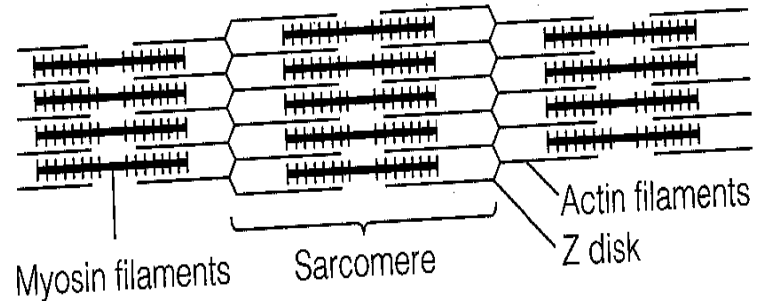
Sarcomere

- Z-discs
 - at the ends of each sarcomere
 - determines length of sarcomere
 - optimal length of muscle is between 2.4 to 2.5 μm
 - very important in terms of force production



Sarcomere

- H-zone
 - German 'Helle' -light
 - central region of the A - band, where there is no filament overlap
 - bisected by M-line which is composed of proteins that keep the sarcomere in proper spatial orientation



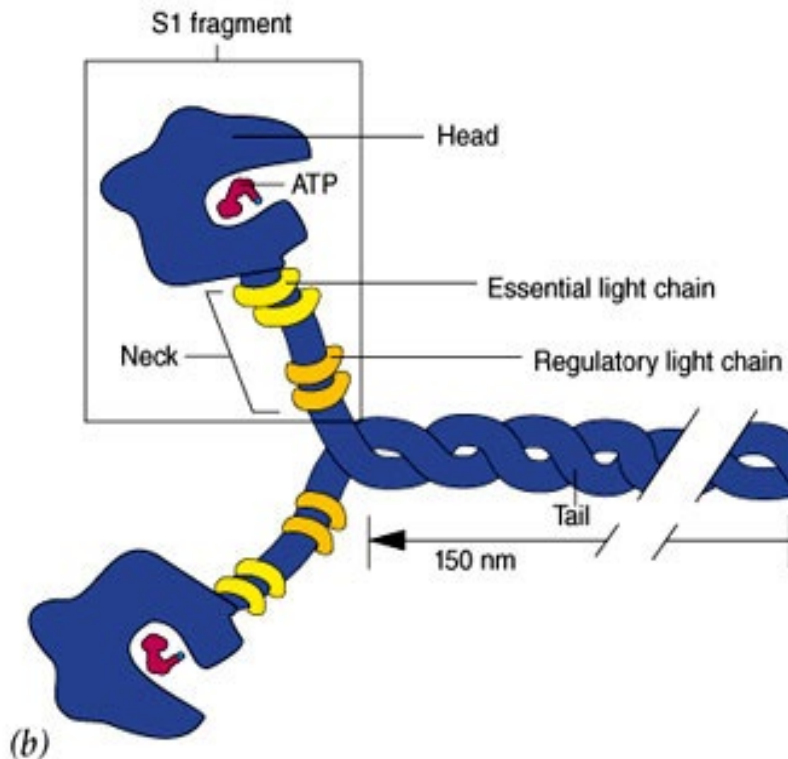
Muscle Cell Moving



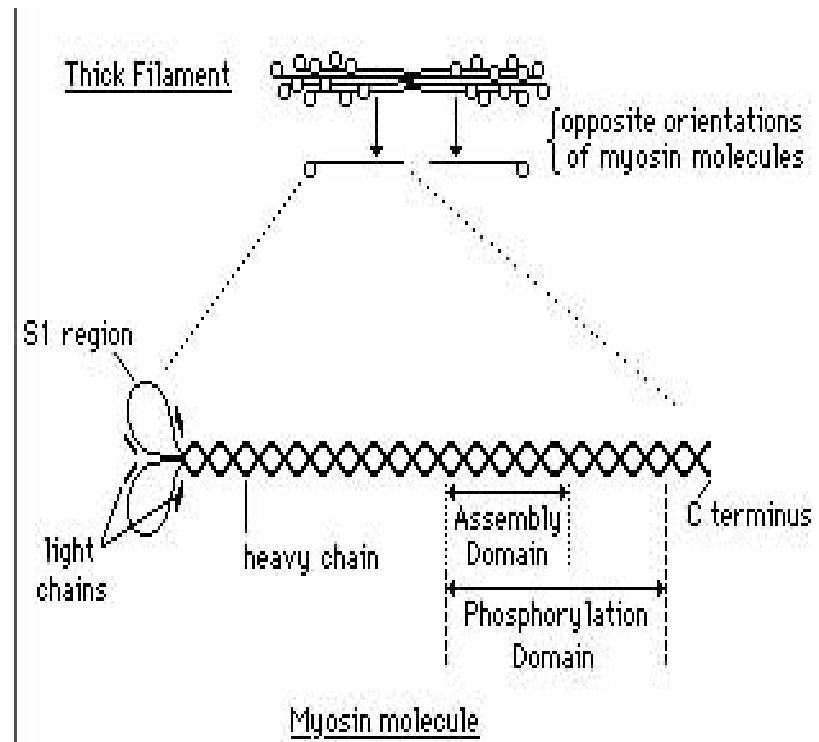
Myosin filaments

- These are the thick filaments and comprise two thirds of the muscle protein. Each myosin filament is formed from approximately 200 myosin molecules lined up end-to-end and side-by-side.
- Each myosin molecule is composed of two protein strands twisted together with one end folded into a globular head, called the myosin head. Each filament contains many such heads which protrude from the filament to form cross-bridges which interact with the actin filaments during contraction.

Structure of the myosin filament



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Actin filaments

- Each actin filament comprising actin, tropomyosin and troponin (has one end fixed in a Z disc and the other extended to the centre of the sarcomere lying between the myosin filaments. Each actin filament contains several active sites to which the myosin head can bind.
- **Tropomyosin** – a contractile protein wound into the grooves of the actin filament blocking the active sites when the muscle is in a resting state and thus preventing actin – myosin interaction.
- **Troponin** – contractile protein bound with the actin that, when activated by calcium released from the sarcoplasmic reticulum, moves tropomyosin away from the active sites on the actin and myosin is then able to cross-bridge with the actin.

Structure of the actin filament

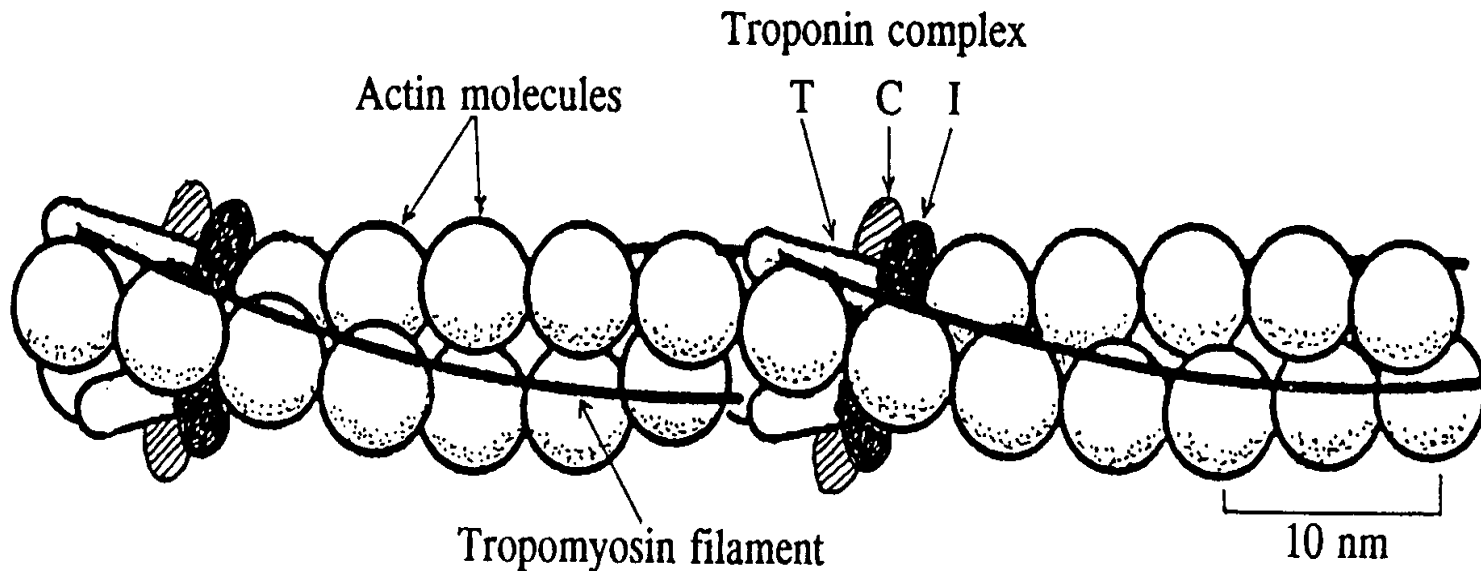
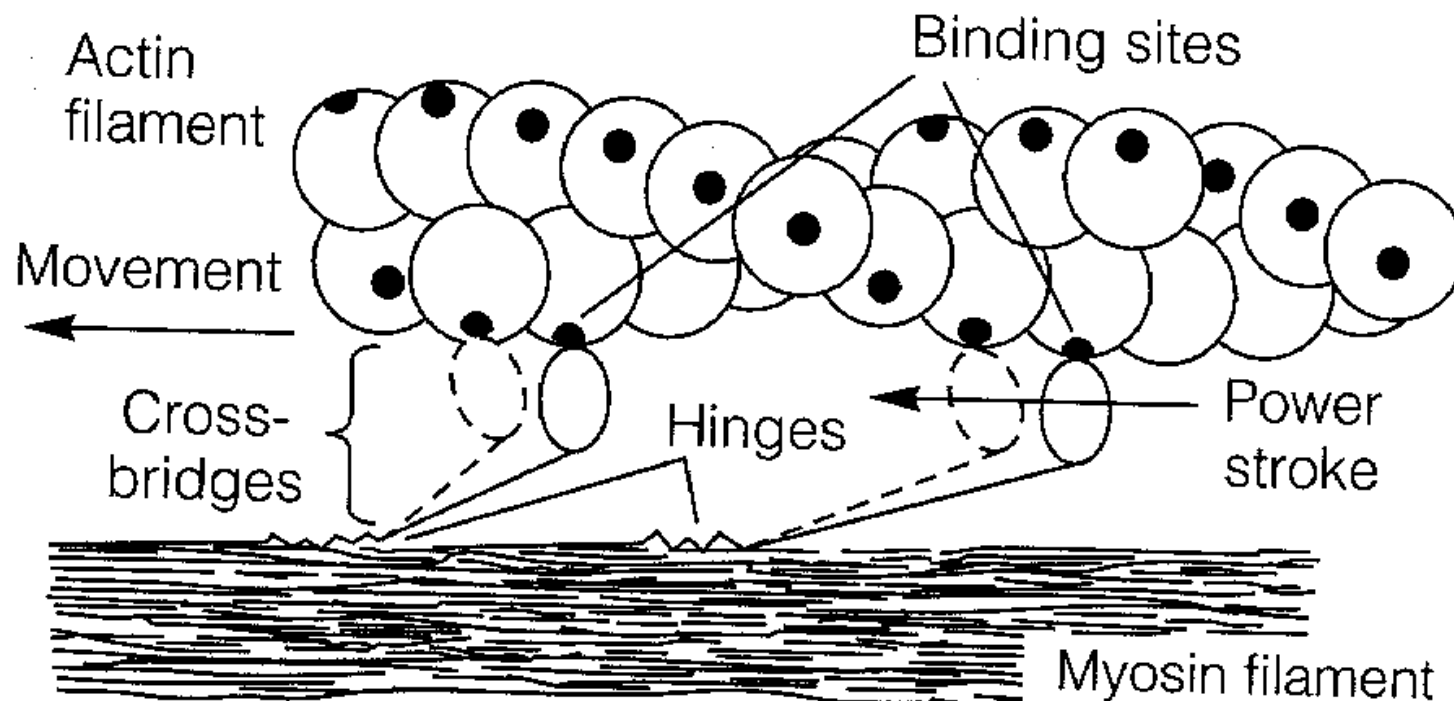


Figure 11.9 Schematic drawing of part of an actin filament showing the relationship between successive pairs of actin molecules, thin filaments of tropomyosin, and the three types of troponin. Another depiction of a (nonmuscle) actin filament is given in Figure 2.4A.

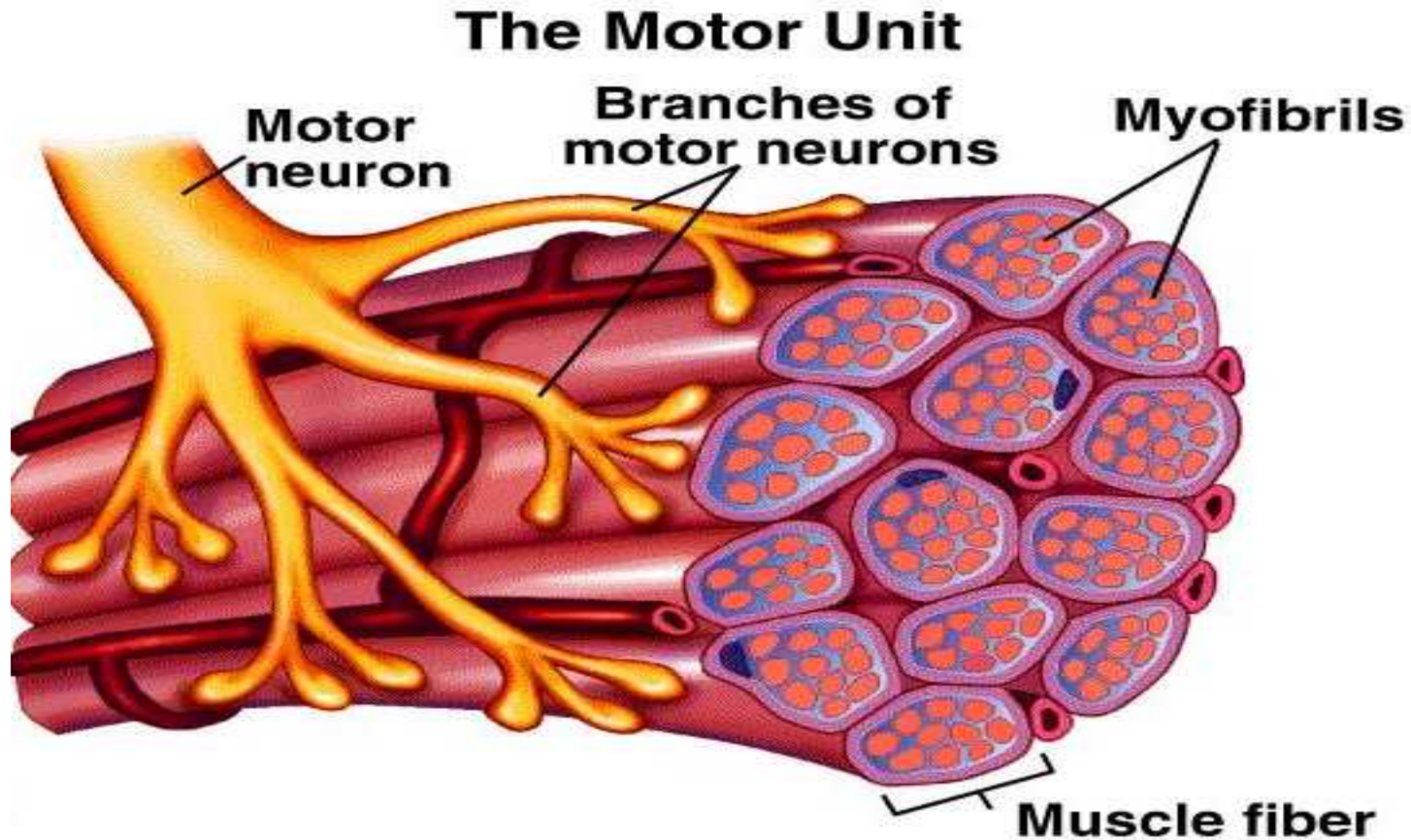
Sliding Filament Theory



Sliding Filament Theory



Control of muscle contraction



Motor Units

- All motor neurons leading to skeletal muscles have branching axons, each of which terminates in a neuromuscular junction with a single muscle fibre. Nerve impulses passing down a single motor neuron will thus trigger contraction in all the muscle fibres at which the branches of that neuron terminate. This minimum unit of contraction is called the **motor unit**.

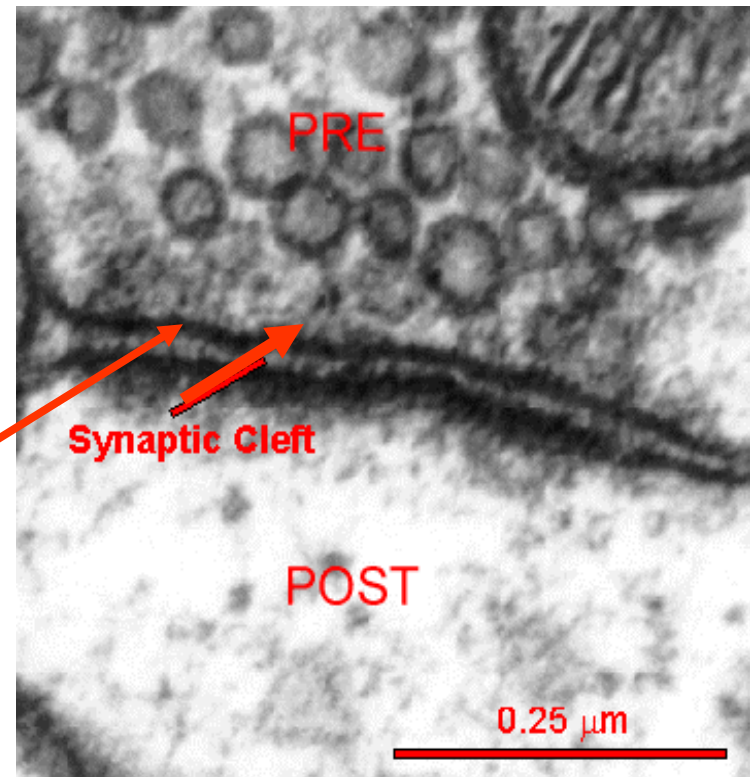
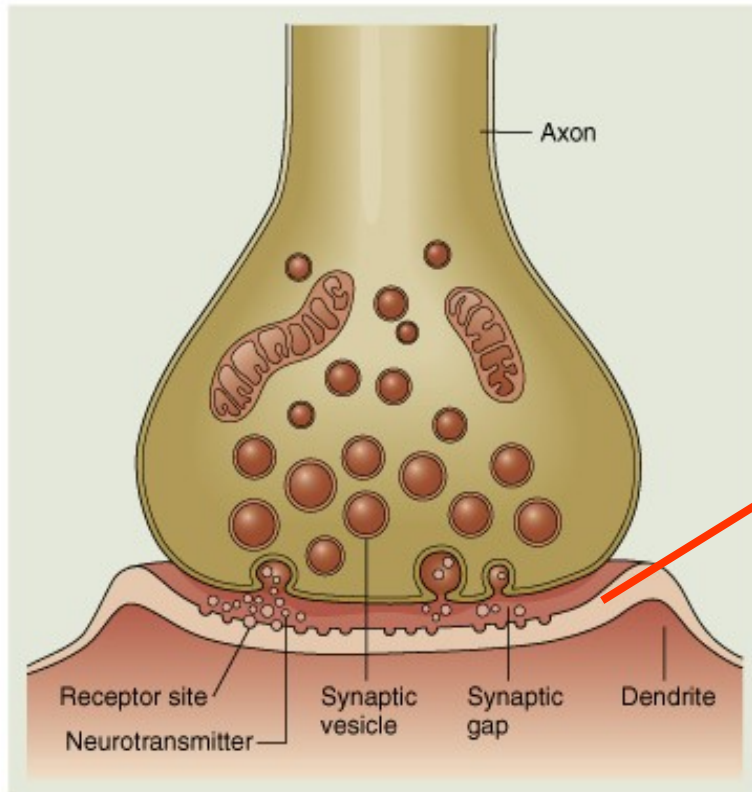
Motor Innervation of Muscles

- The size of the motor unit is small in muscles over which we have precise control.
 - a single motor neuron triggers fewer than 10 fibres in the muscles controlling eye movements
 - the motor units of the muscles controlling the larynx are as small as 2–3 fibres per motor neuron
 - the gastrocnemius (calf) muscle may include 1000–2000 fibres (scattered uniformly through the muscle).
 - 253000 fibres in Biceps Brachii Normal population (Klein 2003)
- Although the response of a motor unit is all-or-none, the strength of the response of the entire muscle is determined by the **number of motor units** activated. Even at rest, most of our skeletal muscles are in a state of partial contraction called **tonus**. Tonus is maintained by the activation of a few motor units at all times even in resting muscle. As one set of motor units relaxes, another set takes over.

Synaptic transmission

- Refers to the propagation of nerve impulses from one nerve cell to another
- This occurs at a specialized cellular structure known as the **synapse - a junction at which the axon of the pre-synaptic neuron terminates at some location upon the postsynaptic neuron**
- Nerve impulses are transmitted at synapses by the release of chemicals called **neurotransmitters**

Transmission between nerve fibres

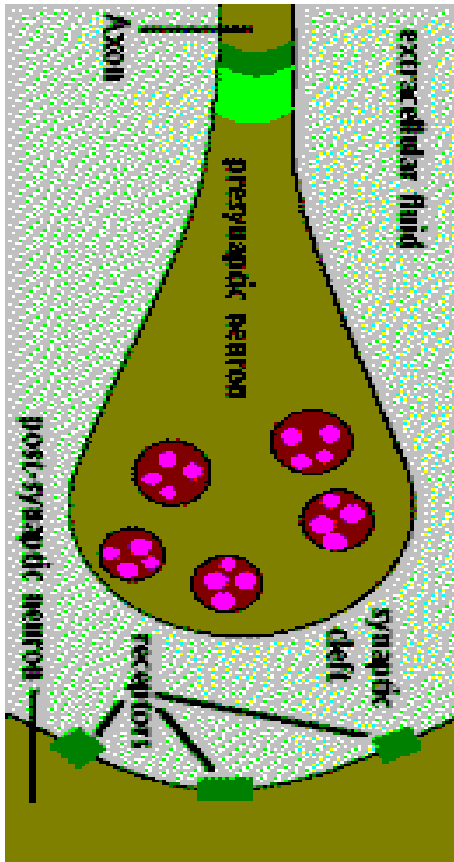


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Synaptic transmission

- When the action potential reaches the terminal region of the pre-synaptic membrane, voltage gated calcium channels open and calcium diffuses down into the pre-synaptic nerve region.
- This increase in calcium concentration results in the migration of acetylcholine containing vesicles to the pre-synaptic membrane.
- The acetylcholine is then released via the process of exocytosis into the synaptic cleft and binds to specialised acetylcholine receptors.
- This opens sodium channels in the postsynaptic membrane allowing sodium to flow into the synaptic cleft. If enough sodium is transferred from into region then the polarity in the receptor region changes and an impulse is generated.

Neuro-muscular transmission



Step 1. The neurotransmitter is manufactured by the neuron and stored in vesicles at the axon terminal

Step 2. When the action potential reaches the axon terminal, it causes the vesicles to release the neurotransmitter molecules into the synaptic cleft

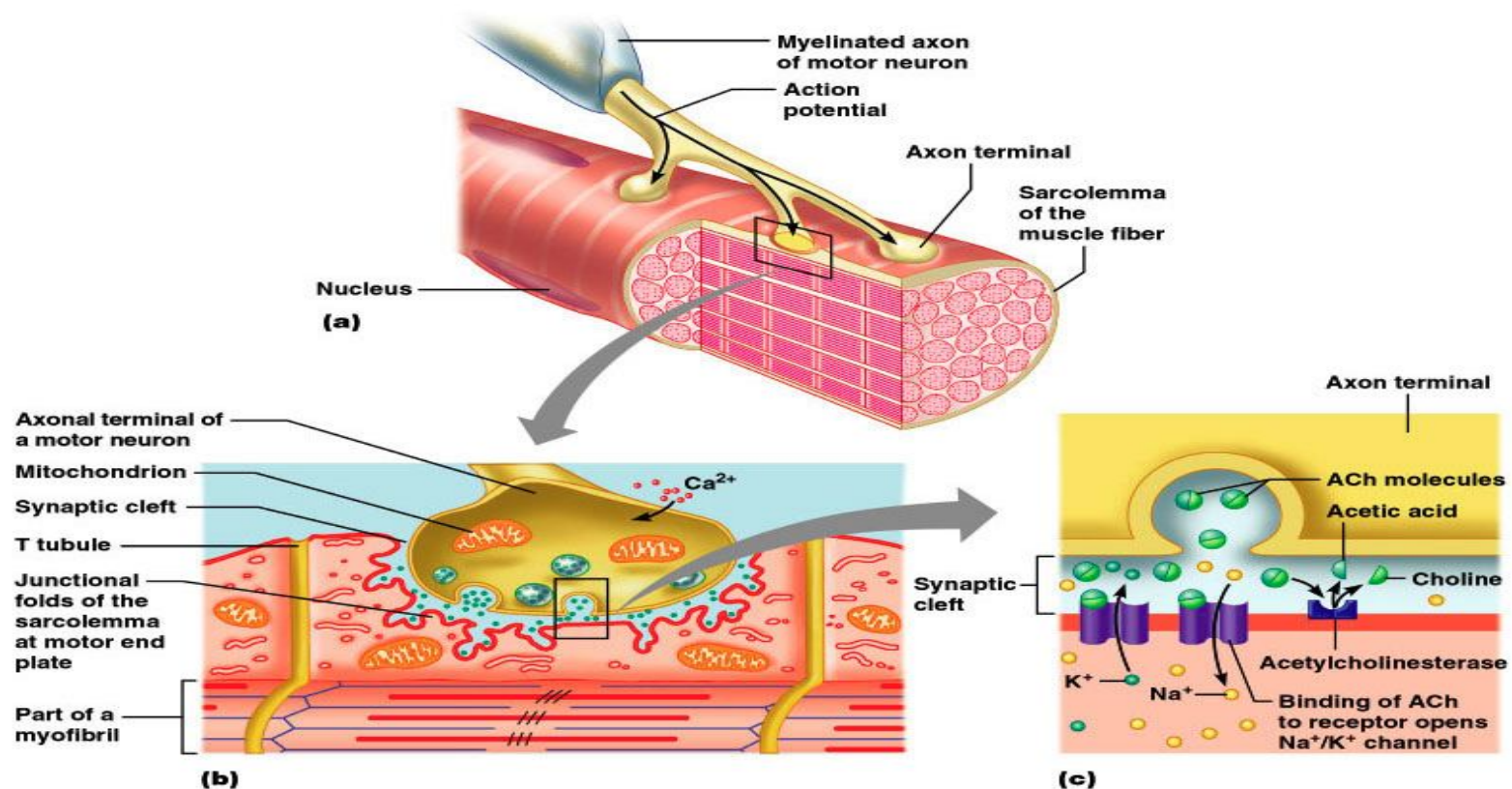
Step 3. The neurotransmitter diffuses across the cleft and binds to receptors on the post-synaptic cell.

Step 4. The activated receptors cause changes in the activity of the post-synaptic neuron.

Step 5. The neurotransmitter molecules are released from the receptors and diffuse back into the synaptic cleft.

Step 6. The Neurotransmitter is re-absorbed by the post synaptic neuron. This process is known as *Reuptake*.

Transmission of Nerve impulse across to a muscle fibre



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Tetanus

- The process of contracting takes some 50 msec; relaxation of the fibre takes another 50–100 msec. Because the refractory (1 msec) period is so much shorter than the time needed for contraction and relaxation, the fibre can be maintained in the contracted state so long as it is stimulated frequently enough (e.g., 50 stimuli per second). Such sustained contraction is called **tetanus**.

Characteristics of Muscle Types

	Type I fibres	Type II A fibres	Type II B fibres
Contraction time	Slow	Fast	Very Fast
Size of motor neuron	Small	Large	Very Large
Resistance to fatigue	High	Intermediate	Low
Activity Used for	Aerobic	Long term anaerobic	Short term anaerobic
Force production	Low	High	Very High
Mitochondrial density	High	High	Low
Capillary density	High	Intermediate	Low
Oxidative capacity	High	High	Low
Glycolytic capacity	Low	High	High
Major storage fuel	Triglycerides	CP, Glycogen	CP, Glycogen

MUSCLE FIBRE COMPOSITION

- MOST MUSCLES HAVE A COMBINATION OF FIBRE TYPES
- GASTROCNEMIUS – HIGH force FAST contraction
- SOLEUS - HIGH force SLOW contraction
- COMPOSITION CHANGES DUE TO TRAINING STIMULUS

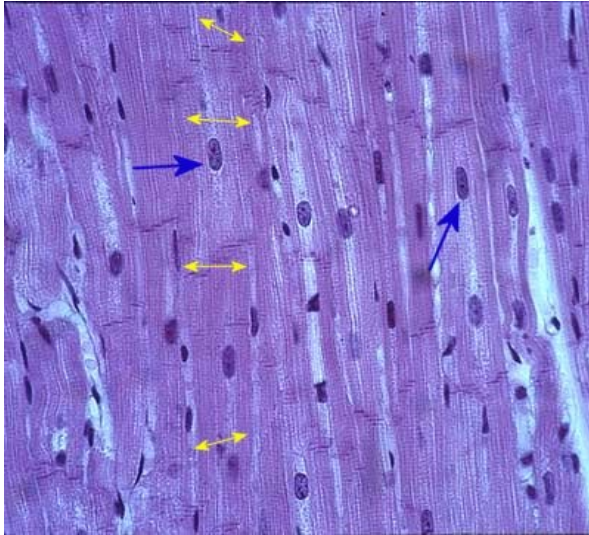
MUSCLE CONTRACTIONS

- ISOMETRIC
 - TENSION - NO MOVEMENT
- ISOTONIC
 - TENSION - MOVEMENT
 - CONCENTRIC - SHORTENING
 - ECCENTRIC - LENGTHENING
- ISOKINETIC
 - SAME SPEED OF MOVEMENT

FACTORS WHICH MODIFY FORCE PRODUCTION

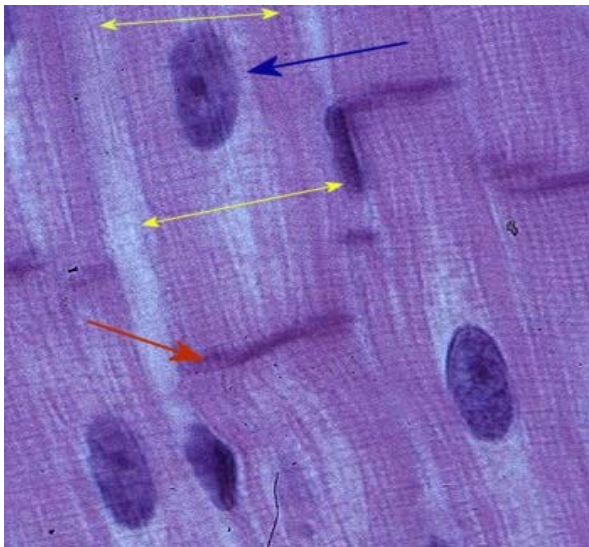
- LENGTH TENSION RELATIONSHIP OF MUSCLE
- FORCE VELOCITY RELATIONSHIP
- MUSCLE FIBRE RECRUITMENT

Cardiac Muscle



Yellow arrows are cardiac muscle fibres

Blue arrows centrally located nuclei



Red arrow – intercollated disc

Smooth Muscle

- found in the walls of all the hollow organs of the body (except the heart). Its contraction reduces the size of these structures and is generally **not** under voluntary control.

Thus, for example it;

- regulates the flow of blood in the arteries
- moves your food along through the gastrointestinal tract
- expels urine from your urinary bladder
- regulates the flow of air through the lungs

Control of smooth muscle

- Smooth muscle is made of single, spindle-shaped cells. It gets its name because no striations are visible in them. Nonetheless, each smooth muscle cell contains **thick** (myosin) and **thin** (actin) filaments that slide against each other to produce contraction of the cell.
- The thick and thin filaments are anchored near the plasma membrane (with the help of intermediate filaments).
- Smooth muscle (like cardiac muscle) does not depend on motor neurons to be stimulated. However, motor neurons (of the autonomic system) reach smooth muscle and can stimulate it — or relax it — depending on the neurotransmitter they release (e.g. noradrenaline or nitric oxide, NO).

- Smooth muscle can also be made to contract by other substances released in the vicinity (paracrine stimulation)
 - Example: release of **histamine** causes contraction of the smooth muscle lining our air passages (triggering an attack of **asthma**)
- by hormones circulating in the blood
 - Example: oxytocin reaching the uterus stimulates it to contract to begin childbirth.
- The contraction of smooth muscle tends to be slower than that of striated muscle. It may also be sustained for long periods. This, too, is called **tonus** but the mechanism is not like that in skeletal muscle.

Comparison between the different muscle types

Characteristic	Skeletal	Cardiac	Smooth
Anatomical location	Attaches to bone or skin	Attaches to fibrous walls of the heart	In or surrounding walls of blood vessels
Multicellular arrangement	Cell (fibres) grouped into fascicles, which comprise the whole muscle	Atrial and Ventricular fibres separated by connective tissue sheath. Single fibres connected to a fibrous skeleton	Single cells within a connective tissue matrix
Cellular morphology	Single, long, cylindric, striated and multinucleated	Branching cells, uninucleated or binucleated and striated	Single, uninucleated and nonstriated
Subcellular morphology	Myofibrils with sarcomeres	Myofibrils with sarcomeres, filaments	Dispersed actin and myosin
Presence/ location of t-tubules	Yes at A-I junctions	Yes at Z lines	No
Sarcoplasmic reticulum	Elaborate	Elaborate	Rudimentary
Gap junctions	No	Yes, intercollacted discs	Yes, in single unit muscle
Regulation of contraction	Voluntary nervous system	Involuntary nervous system. Intrinsic rhythmicity and hormones	Involuntary nervous system, hormones, local chemicals, stretch
Nerve-muscle interaction	Yes, neuromuscular junctions	No	Yes in multiunit muscles
Sources of calcium	Sarcoplasmic reticulum	Sarcoplasmic reticulum and extracellular fluid	Sarcoplasmic reticulum and extracellular fluid
Autorhythmicity	No	Yes	Yes, single unit muscle
Type of contraction	Motor units	Atrial and Ventricular syncytium	Singular or multi-unit
Speed of contraction	Slow to fast	Slow	Very slow
Stretch response	Contraction	Contraction	Relaxation
Metabolism	Oxidative to glycolytic	Oxidative	Mainly oxidative