

# B3.3 MUSCLE AND MOTILITY

Ver. 2

## Guiding Questions

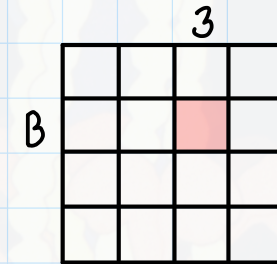
How do muscles contract and cause movement?

What are the benefits to animals of having muscle tissue?

## Linking Questions

What are the advantages and disadvantages of dispersal of offspring from their parents?

In what ways does locomotion contribute to evolution within living organisms?



Theme: *Form and Function*

Level of Organization: *Organisms*


Written and drawn by:

PETER MARIER



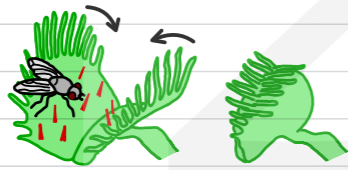
# HL LEARNING OUTCOMES

B3.3.1	Adaptations for movement as a universal feature of living organisms	Students should explore the concept of movement by considering a range of organisms including one motile and one sessile species.
B3.3.2	Sliding filament model of muscle contraction	Students should understand how a sarcomere contracts by the sliding of actin and myosin filaments. The diagram is provided in the data booklet.
B3.3.3	Role of the protein titin and antagonistic muscles in muscle relaxation	The immense protein titin helps sarcomeres to recoil after stretching and also prevents overstretching. Antagonistic muscles are needed because muscle tissue can only exert force when it contracts.
B3.3.4	Structure and function of motor units in skeletal muscle	Include the motor neuron, muscle fibres and the neuromuscular junctions that connect them.
B3.3.5	Roles of skeletons as anchorage for muscles and as levers	Students should appreciate that arthropods have exoskeletons and vertebrates have endoskeletons.
B3.3.6	Movement at a synovial joint	Include the roles of bones, cartilage, synovial fluid, ligaments, muscles and tendons. Use the human hip joint as an example. Students are not required to name muscles and ligaments, but they should be able to name the femur and pelvis.
B3.3.7	Range of motion of a joint	<b>Application of skills:</b> Students should compare the range of motion of a joint in a number of dimensions. Students should measure joint angles using computer analysis of images or a goniometer.
B3.3.8	Internal and external intercostal muscles as an example of antagonistic muscle action to facilitate internal body movements	Students should appreciate that the different orientations of muscle fibres in the internal and external layers of intercostal muscles mean that they move the ribcage in opposite directions and that, when one of these layers contracts, it stretches the other, storing potential energy in the sarcomere protein titin.
B3.3.9	Reasons for locomotion	Include foraging for food, escaping from danger, searching for a mate and migration, with at least one example of each.
B3.3.10	Adaptations for swimming in marine mammals	Include streamlining, adaptation of limbs to form flippers and of the tail to form a fluke with up-and-down movement, and changes to the airways to allow periodic breathing between dives.

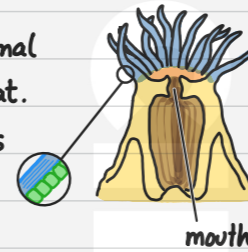
**Movement**: translocation of biomass by an organism's own energy supply in response to a stimulus. Key process of life shared by all living organisms.  cell structure A2.2 However, this is highly variable across organisms

↳ **sessile** organisms remain in a fixed position and are incapable of self-locomotion to move their body from one location to another

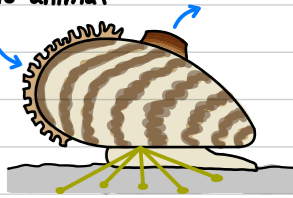
ex: **Venus fly trap (*D. muscipula*)** is a sessile plant living in nitrogen-poor soils  
**adaptation**: leaves with **hair triggers** which once activated, trap insects. Enzymes secreted digest trapped insect in order to absorb nutrients (especially nitrogen)



ex: **Staghorn coral (*A. cervicornis*)** is a marine sessile animal  
**adaptations**: **tentacles** sting and capture plankton to eat. secrete  $CaCO_3$  to form hard exoskeleton. Tissue houses mutualistic photosynthetic **zooxanthellae algae**  
 Coral larvae are motile and become sessile as adults

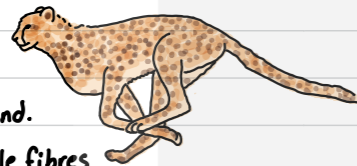


ex: **Zebra mussel (*D. polymorpha*)** is a freshwater sessile animal  
**adaptations**: filter water using **siphons** to take in plankton and nutrients. Attach to substrate using **byssal threads**, securing them in place. Juvenile stages motile

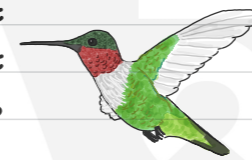


↳ **motile** organisms are able to move their body from one location to another via locomotion

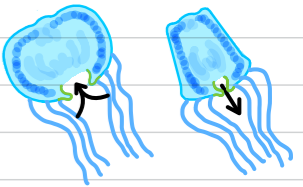
ex: **Cheetah (*A. jubatus*)** is a motile mammal that sprints to hunt.  
**adaptations**: long legs, flexible spine allows large strides. Unretractable claws for traction. Large heart, lungs, liver for increased metabolic demand. Lightweight, small skeleton. A lot of fast-twitch muscle fibres



ex: **Ruby-throated hummingbird (*A. colubris*)** is a motile migratory bird  
**adaptations**: large pectoral muscles to beat wings fast (60x/s). Flexible shoulder joints allow wing movement in a figure-8 pattern allowing hovering and backwards flight. Very small feet to reduce aerodynamic drag.



ex: **Australian box jelly (*C. fleckeri*)** is a marine invertebrate animal  
**adaptations**: to move, they open their bell (increasing volume) and then squeeze it, moving water through a tiny opening (**velarium**) to create a powerful jet for propulsion. Can also easily float



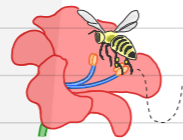
Organisms that are motile have several reasons for locomotion:

● **Foraging for food**: heterotrophic organisms need to acquire energy sources from ingesting other organisms. Locomotion is required to find and/or hunt for these nutritional sources

ex: **Great white shark (*C. carcharias*)** is a marine carnivorous fish  
 Warm body temp. and streamlined bodies allow for efficient swimming and hunting. Very sensitive sense of smell and electroreceptors to detect prey.



ex: **European honey bee (*A. mellifera*)** is a flying pollinating insect.  
 They fly from flower to flower in search for pollen and nectar



● **Searching for a mate**: sexually-reproducing motile organisms require locomotion to find and in some cases attract mates using complex courtship displays

ex: **Western parotia (*P. sefilata*)**: bird of paradise where males engage in a complex courtship dance to attract females; spreading wings like a skirt and shake their head to display ornaments.



ex: **Lion (*P. leo*)**: young males are kicked out of their pride and may wander for years in search of a new pride where they compete with other males for leadership and to reproduce with lionesses



● **Escaping from danger**: most organisms (even predators) have the potential of being prey by another organism, thus locomotion is required to avoid and escape danger.

ex: **Atlantic flying fish (*C. melanurus*)**: marine fish which avoids predation by jumping out of the water and glides using specialized pectoral fins to generate lift.



ex: **Common basilisk (*B. basiliscus*)**: lizard who avoids predation by running across the surface of water by pedaling their legs which have frilled feet



● **Migration**: Some animals journey great distances to another area for food, and/or mating. This may be continuous, yearly or once in a lifetime

ex: **Blue wildebeest (*C. taurinus*)**: mammal who in herds take part in a long-distance migration which follows rainfall and grass growth



ex: **Monarch butterfly (*D. plexippus*)**: insects who over 4 generations migrate between Mexico and Canada due to seasonal changes



ex: **Atlantic salmon (*S. salar*)**: fish which live most of their lives in the ocean but migrate to the rivers they were spawned to reproduce

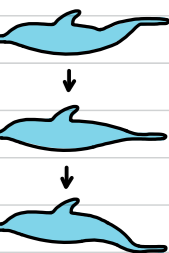
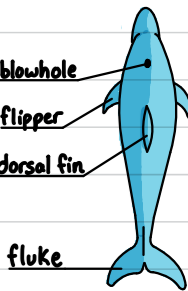


Adaptations for swimming by marine mammals

While most mammals live on land, some species are adapted for life in the ocean. ex: baleen whales, dolphins, orcas

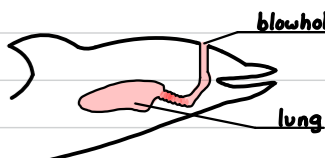
Adaptations:

- ↳ streamlined body shape minimizes underwater drag
- shape widest in front, tapering in rear
- flippers, flukes and dorsal fin have teardrop shape
- body surface is smooth (no ear flaps or body hair)
- ↳ efficient and effective underwater locomotion
- front limbs, flippers for steering
- two lobed fluke tail moves up-down, providing thrust
- dorsal fin provides stability and prevents rolling
- blubber increases buoyancy



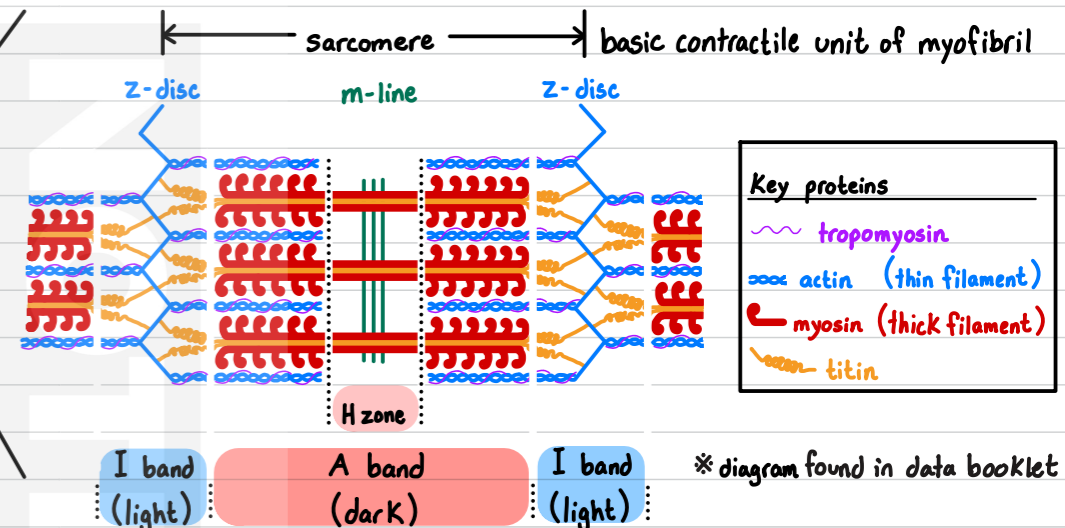
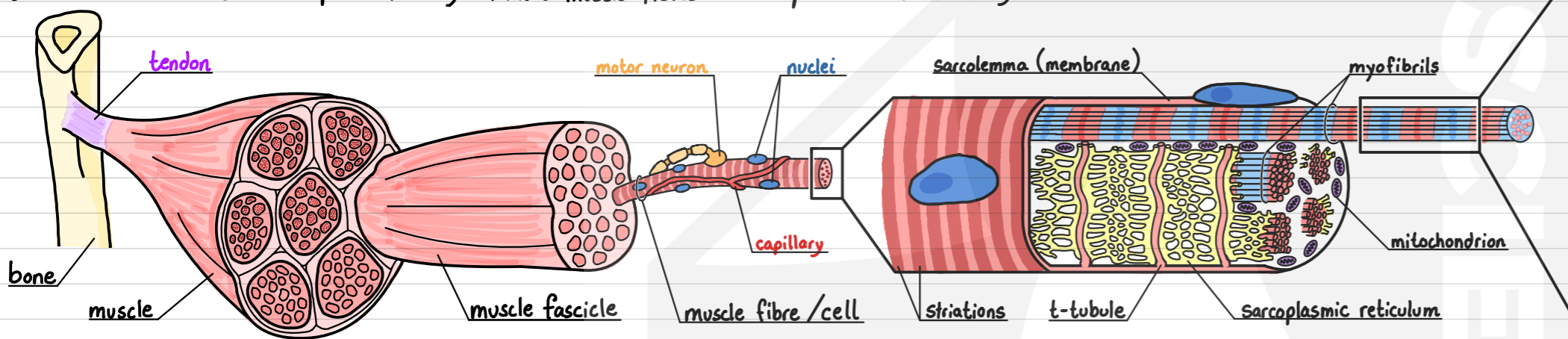
↳ ventilation:

- no connection between mouth and lungs to avoid water entering the lungs
- airway opens to blowhole on the top of body which allows quick breaths and can seal shut during dives



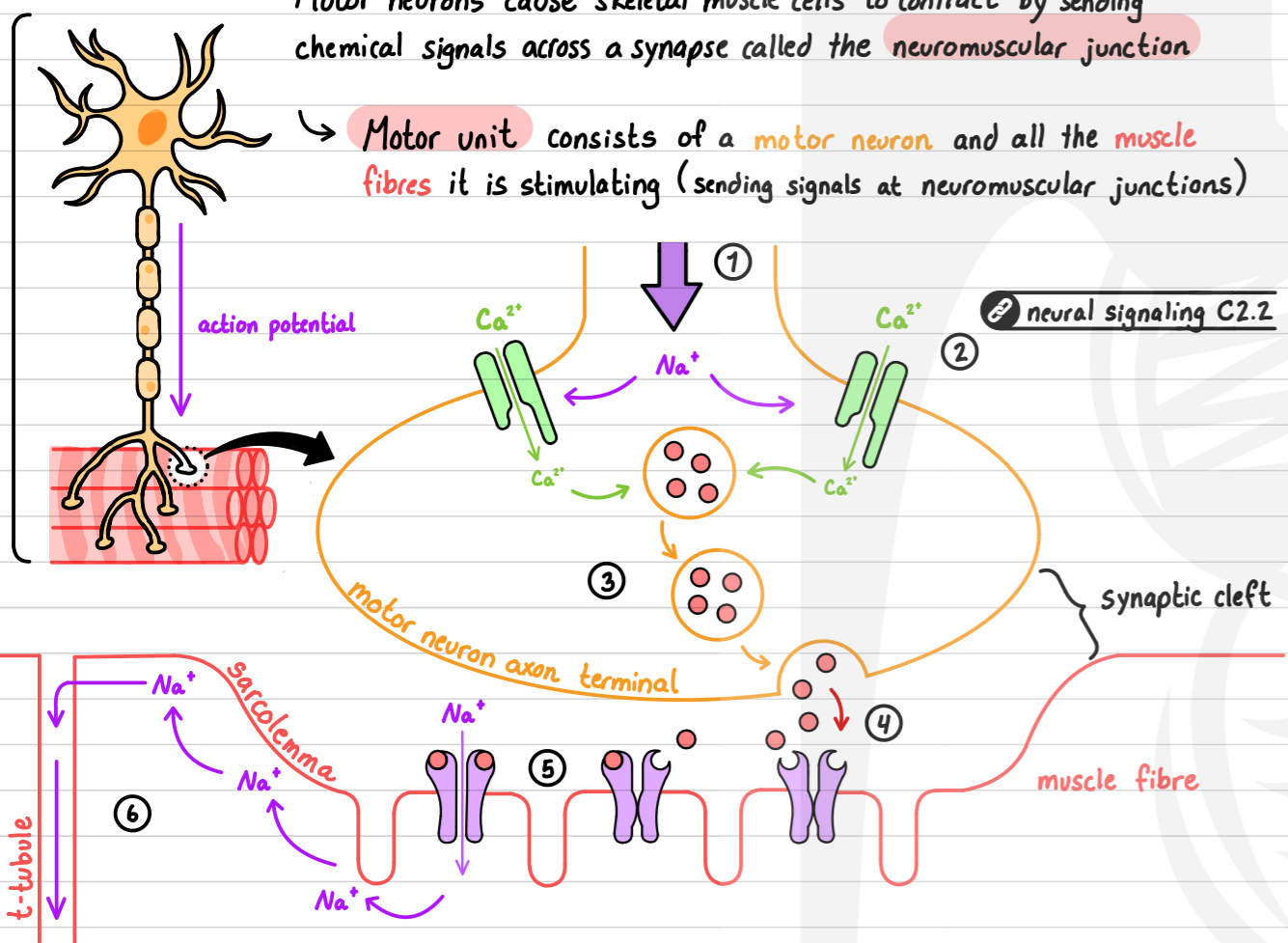
Skeletal muscles are tissues composed of many striated muscle fibres - cells specialized for motility.

cell structure A2.2 cell specialization B2.3



Motor neurons cause skeletal muscle cells to contract by sending chemical signals across a synapse called the neuromuscular junction

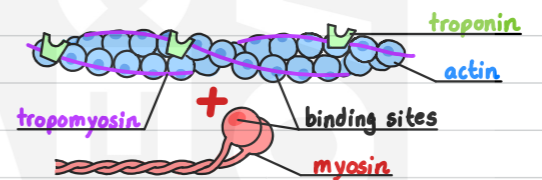
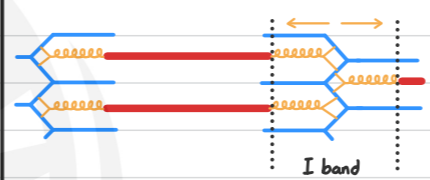
Motor unit consists of a motor neuron and all the muscle fibres it is stimulating (sending signals at neuromuscular junctions)



- 1 action potential arrives at axon terminal of motor neuron
- 2 voltage-gated  $Ca^{2+}$  channels open causing  $Ca^{2+}$  influx
- 3  $Ca^{2+}$  trigger synaptic vesicles to fuse with axon membrane
- 4 Acetylcholine (neurotransmitter) released via exocytosis and diffuses
- 5 ACh binds to nicotinic ACh receptors causing  $Na^{+}$  influx
- 6 action potential is propagated along sarcolemma, down t-tubule
- 7 sarcoplasmic reticulum releases stored  $Ca^{2+}$ , initiating muscle contraction

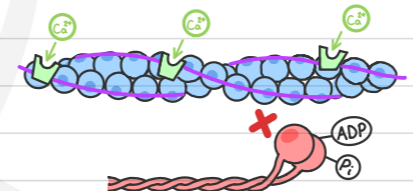
Sliding filament model of muscle contraction explains how muscle fibres shorten during contraction and lengthen during relaxation through the sliding of actin (thin filaments) and myosin (thick filaments) in a sarcomere.

Muscle relaxation



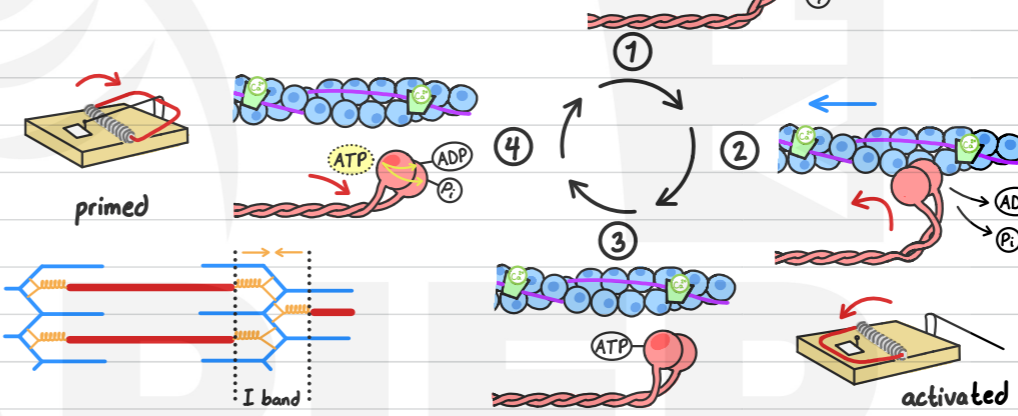
$Ca^{2+}$  is not bound to troponin, allowing tropomyosin to block the binding sites on actin, preventing myosin from binding  
 → little overlap of filaments ∴ large light (I) band  
 → sarcomere is long, titin, an elastic protein is stretched (unfolded) storing potential energy

Initiating muscle contraction



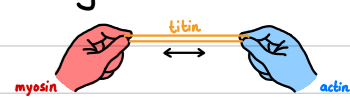
$Ca^{2+}$  from sarcoplasmic reticulum binds to troponin causing a conformational change in tropomyosin, exposing actin binding sites allowing cross-bridge formation  
 \* once calcium is depleted or neural signal stops, tropomyosin reverts back

Power stroke cycle



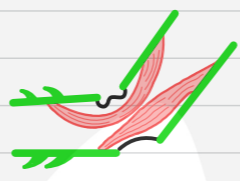
- 1 myosin heads and actin form cross-bridge
  - 2 power stroke: ADP +  $P_i$  unbind, causing myosin to bend, pulling actin towards m-line (center)
  - 3 ATP binds to myosin head causing cross-bridge to break, releasing myosin from actin
  - 4 ATP is hydrolyzed to ADP +  $P_i$ , releasing energy which cocks myosin head (storing potential energy)
- \* 1-4 repeated, bringing z-discs closer together  
 → titin recoils back (folds), releasing energy and adding force Sarcomere shortens

\* energy is needed to stretch titin during relaxation and lengthen a muscle but muscles can only exert force during contraction  
 ∴ muscles work in antagonistic pairs: titin stretches in a relaxed muscle when its antagonist is contracted  
 in addition, titin has a structural role, holding myosin in place and prevents sarcomere from overstretching

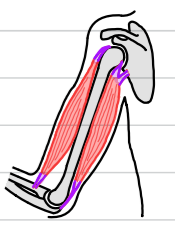


Skeleton acts as a structural framework that supports and protects an animal's body and internal organs. It is attached to muscles which allows movement

• **exoskeleton**: skeleton on the outside of an organism's body. Typically made of chitin and/or CaCO<sub>3</sub> muscles attached on the inside of the skeleton, consisting of many connected segments  
ex: arthropods (insects, arachnids, crustaceans, myriapods)



• **endoskeleton**: skeleton on the inside of an organism's body. Composed of many bones muscles attached to outside of bones via tendons  
ex: vertebrates (mammals, birds, reptiles, amphibians, fish)



↳ skeletons facilitate movement by providing anchorage for muscles and acting as levers

**effort**: force applied to move load

**load**: what is moved

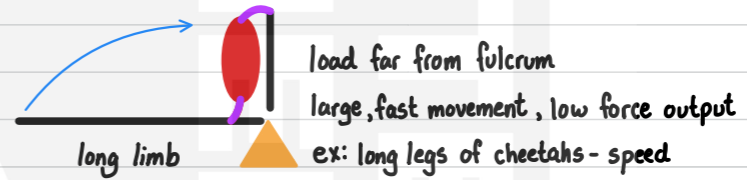
**fulcrum**: fixed pivot point



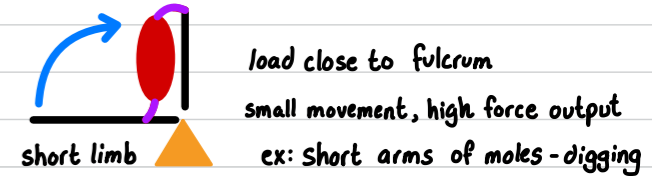
**lever**: rigid bar on a fulcrum



↳ lever trades force for movement → effort further from fulcrum, less muscle force needed but smaller movement (+vice-versa)



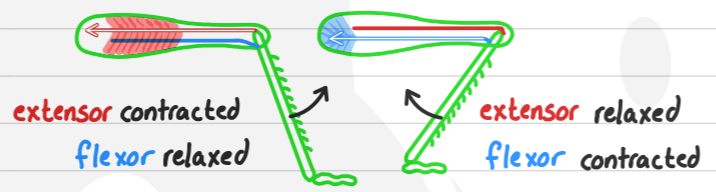
load far from fulcrum  
large, fast movement, low force output  
ex: long legs of cheetahs - speed



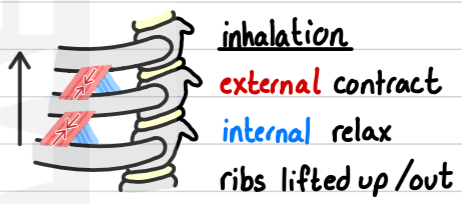
load close to fulcrum  
small movement, high force output  
ex: short arms of moles - digging

When muscles contract they exert force by shortening which pulls the bone it is attached to. However they cannot exert force to relax and lengthen, thus they work in **antagonistic pairs** when one muscle contracts, its antagonist relaxes, allowing titin to stretch and store potential energy for future contraction

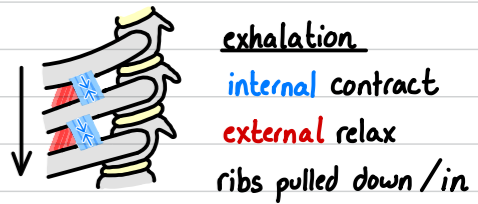
ex: grasshopper legs move with extensor and flexor muscles



ex: **external and internal** intercostal muscles work antagonistically due to their opposite fibre orientation causing opposite movement

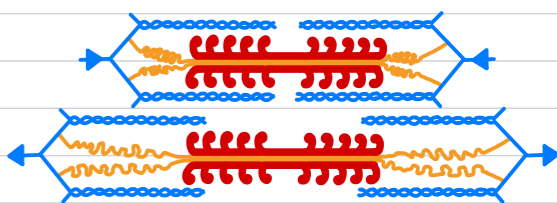


**inhalation**  
external contract  
internal relax  
ribs lifted up/out



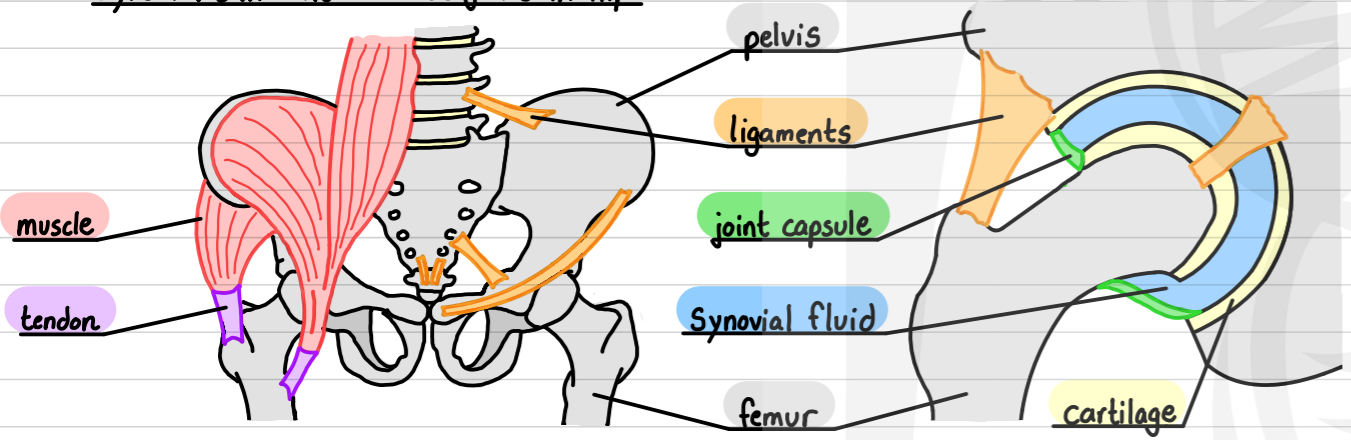
**exhalation**  
internal contract  
external relax  
ribs pulled down/in

⊗ as one muscle contracts it stretches **titin** in sarcomere of antagonist



Bones meet at joints. Most joints allow bones to move in relation to each other (articulation) - most common are **Synovial joints**

↳ **Synovial ball-and-socket joint in hip**

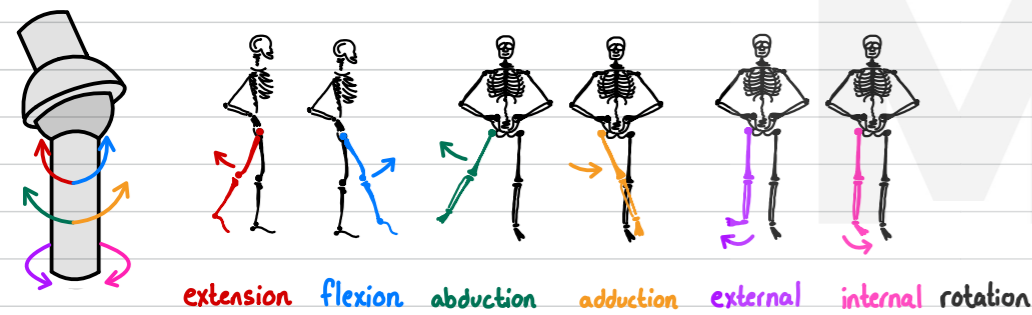


↳ **Synovial ball-and-socket joint in hip: functions**

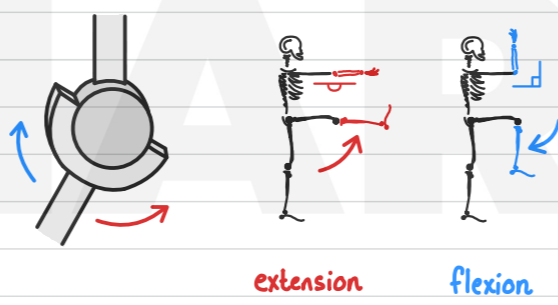
- Bones**: provide anchorage for muscles. Femur acts as 'ball' and pelvis acts as 'socket' in joint to allow movement
- Cartilage**: smooth tissue which covers the bone at joints to reduce friction and absorb shock, preventing injury
- Synovial fluid**: fluid within cavity of joint which acts as a lubricant to reduce friction
- Joint capsule**: tough covering which seals the joint cavity, holding synovial fluid
- Ligaments**: tough connective tissue which connects bones together preventing dislocation
- Muscles**: contract to provide force which cause movement
- Tendons**: tough connective tissue which connects muscle to bone allowing transmission of force from contractions

The type and structure of a joint dictates its **range of motion**: extent to which a body part can be moved around a joint → can be measured with a **goniometer** or with computer analysis of images or apps using gyroscopes

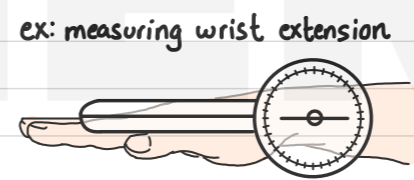
↳ ball-and-socket joints allow range of motion in 3 planes:



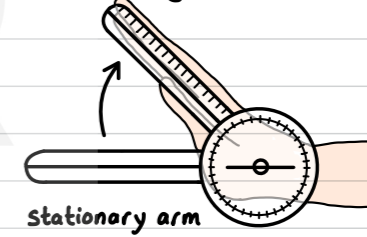
↳ hinge joints only allow movement in one plane:



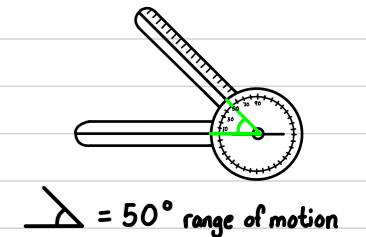
① align center of goniometer with joint being measured. Keep 1 arm stationary



② move other goniometer arm to align with moving limb during motion



③ read angle on goniometer to determine range of motion of joint

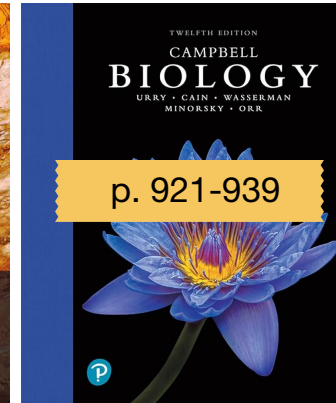
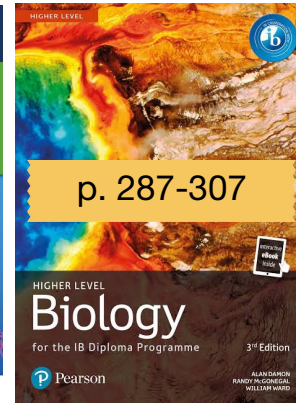
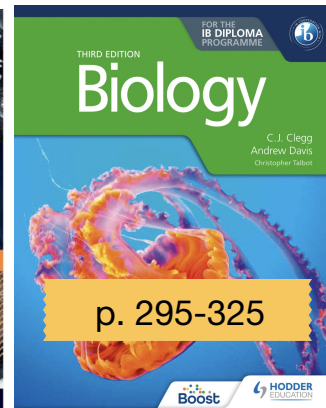
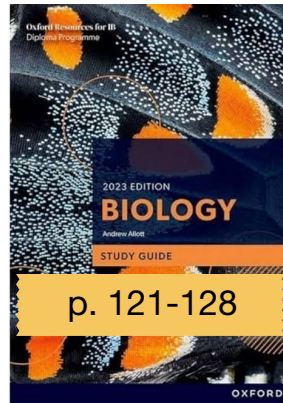
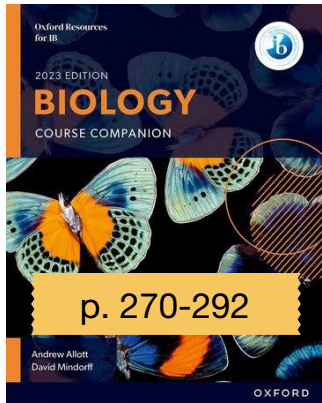


# Resource Links

each resource is hyperlinked



## Textbooks



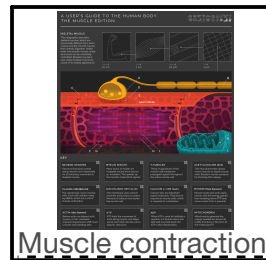
## Simulators / Interactives

**Flex your Muscles!** Model an antagonistic muscle pair (biceps and triceps) and learn about flexors vs. extensors.

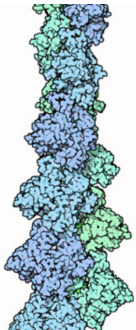
**Muscle Structure** Learn about the structure of skeletal muscle tissue. This will help you understand how it functions!

**How Muscles Contract** Learn about the structure of skeletal muscle tissue. This will help you understand how it functions!

Muscle contraction



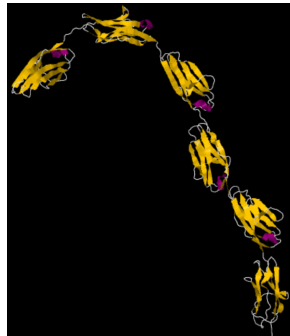
## 3D models



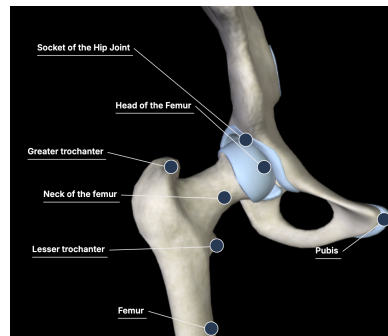
Actin



Myosin



Titin



Human hip

## Articles

Fernández, J. M. (2018, September 1). Opinion: Stop ignoring this filament crucial to muscle function. *The Scientist*. <https://www.the-scientist.com/opinion--stop-ignoring-this-filament-crucial-to-muscle-function-64689>

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Neumann, D. A. (2010). Kinesiology of the Hip: a focus on muscular actions. *Journal of Orthopaedic and Sports Physical Therapy*, 40(2), 82–94. <https://doi.org/10.2519/jospt.2010.3025>

Powers, J. D., Malingen, S. A., Regnier, M., & Daniel, T. L. (2021). The Sliding Filament Theory Since Andrew Huxley: Multiscale and Multidisciplinary muscle research. *Annual Review of Biophysics*, 50(1), 373–400. <https://doi.org/10.1146/annurev-biophys-110320-062613>