B3.3 Teacher view

Muscle and motility (HL)

Index

The big picture (HL)

Higher level (HL)

? Guiding question(s)

- How do muscles contract and cause movement?
- What are the benefits to animals of having muscle tissue?

Keep the guiding questions in mind as you learn the science in this subtopic. You will be ready to answer them at the end of this subtopic. The guiding questions require you to pull together your knowledge and skills from different sections, to see the bigger picture and to build your conceptual understanding.

All living things, whether big or small, whether motile or sessile, have the ability to move at some point in their life cycle. This includes barnacles – small crustaceans that are known for their ability to stick to hard surfaces (**Figure 1**).

Figure 1. *Semibalanus balanoides,* also known as common barnacles, common rock barnacles or acorn barnacles.

Credit: Catherine McQueen, Getty Images (https://www.gettyimages.com/detail/photo/coastal-rocks-coated-with-live-barnacles-royalty-free-image/1255246576)

In their larval stage, barnacles exhibit complex swimming behaviours that allow them to disperse and swim to new locations before adhering to hard surfaces and becoming sessile adults. Although they cannot move from location to location, barnacles still retain some movement; they can use small pairs of muscles to extend or retract their feeding appendages to catch plankton and other small organisms, as shown in **Video 1**.

How do muscles contract and allow animals to move? And what are the benefits of movement?

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Video 1. Feeding behaviour of barnacles.

More information for video 1

The video provides a fascinating look at how barnacles, despite being permanently attached to surfaces, effectively feed using specialized anatomical adaptations.
The text at the beginning of the video reads "BARNACLES: they start their lives as plankton, but plankton is also what they eat." It further reads "The following footage shows Barnacle feeding behavior in normal and slow motion." The footage shows a bunch of barnacles feeding in normal and slow motion while being attached to a hard surface. It shows hair-like appendages, the cirri, capturing plankton efficiently by rapidly flicking out and retracting when disturbed. Close-up footage of waste, undigested material (as a smoky cloud) being ejected via contractile movements of the body is also shown.

Prior learning

Before you study this subtopic make sure that you understand the following:

- Understanding movement as one of the processes of life (see section A2.2.7 (/study/app/bio/sid-422-cid-755105/book/processes-of-life-in-unicellular-organisms-id-44688/))
- Neural signalling (see subtopic C2.2 (/study/app/bio/sid-422-cid-755105/book/big-picture-id-43541/))
- Brain—muscle connection (see section C3.1.7 (/study/app/bio/sid-422-cid-755105/book/sensory-and-motor-neuronsome-id-44822/))
- Adaptations of cardiac muscle cells and striated muscle fibres (see section B2.3.9 (/study/app/bio/sid-422-cid-755105/book/checklist-id-44811/)).

B3. Form and function: Organisms / B3.3 Muscle and motility (HL)

Movement as a universal feature of living organisms (HL)

B3.3.1: Adaptations for movement (HL)

Section Student... (0/0) Feedback Print (/study/app/bio/sid-422-cid-755105/book/movement-as-a-universal-feature-of-living-hl-id-44814/print/) Assign

Higher level (HL)

Learning outcomes

By the end of this section you should be able to recognise the concept of

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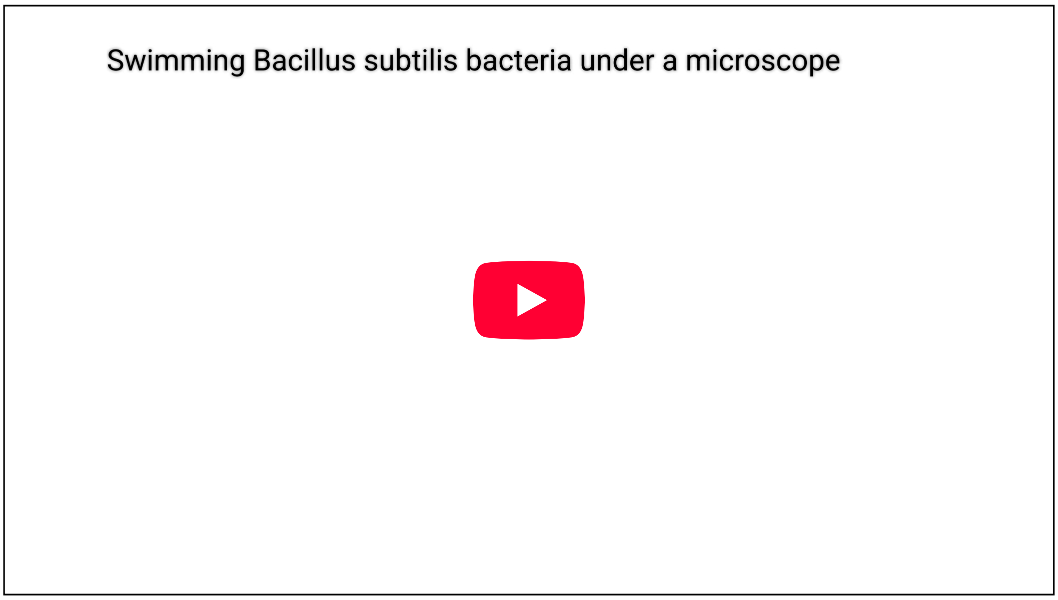
movement in different species.

Movement is a universal feature of living organisms. Whether an organism is multicellular or unicellular, complex or simple, motile or sessile, they will demonstrate movement in some form (see section A2.2.7 (/study/app/bio/sid-422-cid-755105/book/processes-of-life-in-unicellular-organisms-id-44688/)). But what is movement? What is its purpose? And how do sessile organisms demonstrate movement?

Movement is the change in position or location of an organism or body part relative to its surroundings. It can be voluntary or involuntary and can occur in response to internal or external stimuli.

Movement allows organisms to interact with their environment, obtain resources, find mates, respond to threats and engage in social behaviours.

Motile organisms have the ability to actively move from one place to another, allowing them to perform various functions such as avoiding danger, finding a mate, migrating and foraging for food. Mammals, for instance, use skeletal muscles to run, walk, jump and swim from one place to another, while wings are used by birds and insects to fly. There are other means of locomotion, such as flagella, whip-like structures found in bacteria that can rotate to propel the organism forward, as shown in **Video 1**.



Video 1. Motility of flagellated bacteria.

More information for video 1

Microscopic footage reveals some Bacillus subtilis cells darting and tumbling, demonstrating their ability for rapid changes in direction, while a few cells remain stationary.
Bacillus subtilis use whip-like appendages called flagella, for motility. These rotate like propellers powered by a

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molecular motor at the base (fuelled by proton gradients). The purposes of bacterial motility include resource acquisition (swim towards nutrients or away from toxins) and threat avoidance (escape predators or harmful environments).
The footage shows flagellar motility.

Squids and octopuses can use jet propulsion to move through water, expelling a jet of water through a muscular tube, which propels the organism in the opposite direction. The direction of this tube can be controlled, which allows the organism to change and control direction. Watch **Video 2** to see jet propulsion in action.

Video 2. Jet propulsion in the California two-spot octopus (*Octopus bimaculoides*).

More information for video 2

The video provides a visual demonstration of how octopuses use jet propulsion to navigate underwater. The video begins with an octopus lying motionless on the ocean floor, its skin blending seamlessly with the surrounding environment. The sandy, rocky seabed and the patches of sparse vegetation create a visually complex backdrop. After a brief moment of stillness, the octopus suddenly propels itself forward using a powerful jet of water. The burst disturbs the sand beneath it, creating a temporary cloud that briefly obscures the view. This action visually reinforces the concept of jet propulsion, as the movement is driven by the strong expulsion of water from the specialized muscular tube in the opposite direction of travel.
As the octopus moves, it pauses intermittently, changing its skin color to a deeper reddish-brown. The camera follows the octopus as it continues its journey, releasing another jet of water and stirring up additional sediment in its way.
At one point, the octopus releases a dark, ink-like substance into the water before swiftly propelling itself forward again. The momentary cloud of ink disperses as the octopus moves farther away.
The final moments of the video depict the octopus gradually fading into the distance as the water clears once more. The camera lingers on the seabed, emphasizing the stillness of the ocean floor in contrast to the dynamic motion observed moments before.

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Sessile organisms are those that are fixed to one place. Sessile organisms rely on the environment to bring food and other resources to them. Like barnacles, the example given in The big picture (/study/app/bio/sid-422-cid-755105/book/big-picture-hl-id-43535/), plants are examples of sessile organisms. Although they cannot move from one place to another, sessile organisms can exhibit movement in response to external stimuli, such as the growth of a plant stem towards the light. Another example is the plant *Mimosa pudica* folding its leaves and drooping its stem, as shown in **Video 3**, a response thought to deter herbivores and insects from eating the plant.

Video 3. *Mimosa pudica* moving in response to touch.

More information for video 3

The video begins with a close-up of a Mimosa pudica plant in a red pot placed against a neutral gray background. The viewer witnesses a gentle fingertip approaching one of the plant's delicate, fern-like leaves. Upon contact, the leaf responds instantly, folding inward in a rapid, visually striking motion. This movement illustrates a clear example of a sessile organism exhibiting responsiveness to external stimuli. Though fixed in place, the plant actively reacts to its environment.

To emphasize the before-and-after contrast, a split-screen view follows. On the left side, the leaf remains open; on the right, it is fully closed following touch. A vertical black bar divides the screen, and both sides are set against a black background to draw focus to the dynamic change.

The video then presents another close-up view of a single mimosa leaf isolated against a stark black background, enhancing the visibility of its intricate leaflet structure. A fingertip once again gently touches a leaflet, and the plant responds with swift inward folding. This highlights the plant's ability to sense and react to mechanical stimuli through rapid cellular processes, despite being unable to relocate.

The final segment of the video uses a three-way split-screen format to show Mimosa pudica at three different stages of response: fully open, partially closed, and completely closed. Each plant is situated in a unique setting, from terracotta pots with red-brown pellets to decorative containers, demonstrating the same reaction to touch in varied contexts. Each of the three views features a fingertip triggering the closing motion.

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Creativity, activity, service

Strands: Activity and Service
Learning outcome: Show commitment to, and perseverance in, CAS experiences

Physical movement is essential for maintaining a healthy lifestyle, both physically and mentally. Organising or taking part in a physical challenge that collects money for a cause can help you contribute to the wellbeing of others while also developing your own capabilities.

Possible ideas:

- Organise a fun run or walk for your school or local community.
- Organise an inter-house competition within your school.
- Join a pre-existing challenge such as a triathlon or mud run.
- Host a yoga or exercise class.
- Plan a fitness challenge, such as a push up challenge or a plank challenge.

Try the activity below in pairs to research one motile and one sessile organism.

Activity

- **IB learner profile attribute:** Inquirer
- **Approaches to learning:** Research skills — Using search engines and libraries effectively
- **Time required to complete activity:** 20 minutes
- **Activity type:** Pair activity

Research movement in one motile and one sessile organism of your choice. For each organism, write a paragraph discussing:

- How that organism is adapted to move.
- The functions of movement in that organism.

Student view

5 section questions

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B3. Form and function: Organisms / B3.3 Muscle and motility (HL)

Muscle contraction (HL)

B3.3.2: Sliding filament model of muscle contraction (HL) B3.3.3: Role of the protein titin and antagonistic muscles (HL)
B3.3.4: Structure and function of motor units in skeletal muscle (HL)

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Higher level (HL)

Learning outcomes

By the end of this section you should be able to:

- Outline the structure of a sarcomere.
- Explain how a sarcomere contracts.
- Outline the role of titin and antagonistic muscles in muscle relaxation.
- Describe the structure and function of motor units in skeletal muscles.

Take a look at some of the Guinness World Records (https://www.guinnessworldrecords.com/news/2021/1/11-of-the-most-hardcore-fitness-records-ever-645867) for human fitness and you cannot fail to appreciate that muscles are amazing. Viewed under a microscope, skeletal muscle, the muscle that is attached to bones to facilitate movement, appears striated (striped). The cells that make up our skeletal muscles are elongated, multinucleate and contain many mitochondria (see section B2.3.7–10 (/study/app/bio/sid-422-cid-755105/book/checklist-id-44811/) for more information about adaptations of striated muscle fibres). But what do these cells contain to make them striated? And how do these atypical cells (see section A2.2.8–11 (/study/app/bio/sid-422-cid-755105/book/animal-plant-and-fungal-cells-id-44719/)) generate the force necessary for muscle contraction?

The structure of a sarcomere

Within muscle cells are thread-like structures called myofibrils, which are composed of repeating units called sarcomeres.

Sarcomeres are composed of two types of protein filaments: thick filaments (myosin) and thin filaments (actin), the alternating arrangement of which gives skeletal muscle its striated look (**Figure 1**).

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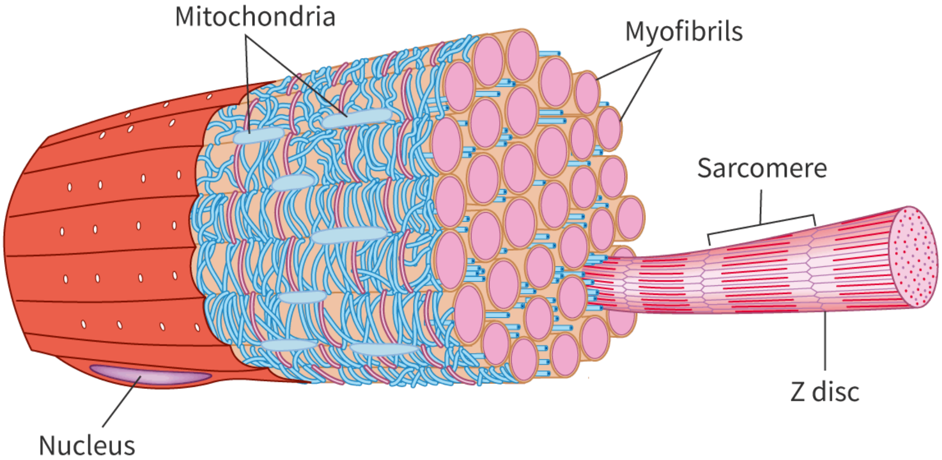

Figure 1. The structure of a muscle.

More information for figure 1

The image is a detailed illustration of muscle structure. It shows a cylindrical muscle fiber cut halfway along its length to reveal internal structures. The outer part of the muscle is composed of multiple rounded cross-sections, indicating myofibrils that run parallel along the muscle fiber. Labels identify key components: 'Mitochondria' are depicted within the fiber, 'Myofibrils' are shown as cylindrical units, and a labeled section 'Sarcomere' indicates the repeating functional unit of the muscle. The diagram also identifies the 'Z disc', shown as a boundary within the myofibrils, and the 'Nucleus' positioned towards the outer part of the muscle. This visual representation conveys the arrangement and organization of the muscle's internal components, focusing on the structural relationship between these elements.

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The boundaries of a sarcomere are defined by the Z discs, which organise and anchor the actin filaments. The space between the Z discs is known as the sarcomere length. In the centre of the sarcomere is the M line, which organises and anchors the myosin filaments (**Figure 2**).

The I bands are regions of the sarcomere where only actin filaments are present, located on either side of the Z disc. The A band is the region where myosin is present, and contains an area of overlap between actin and myosin, as well as an area in the middle of the sarcomere containing only myosin called the H band.

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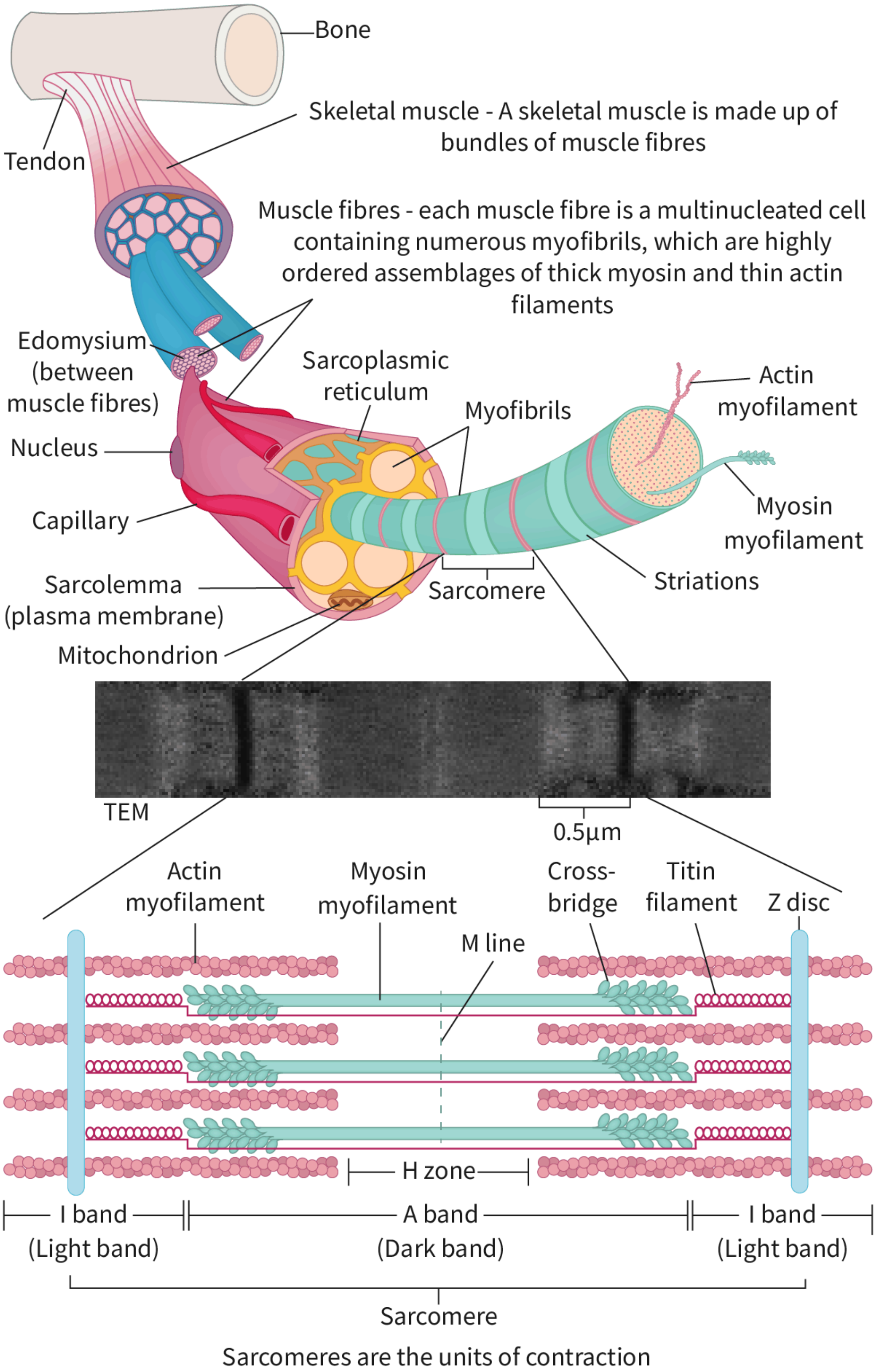

Figure 2. The structure of a sarcomere.

More information for figure 2

The image is a detailed diagram illustrating the structure of skeletal muscle and the sarcomere. At the top left, a section of bone is shown with a tendon attached to it, connecting to bundles of muscle fibers. These fibers are depicted as cylindrical structures and contain various components. An inset shows muscle fibers, each being a multinucleated cell that contains numerous myofibrils, described as ordered assemblages of thick myosin and thin actin filaments.

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On the right, a close-up visualizes the sarcomere, detailing its specific zones and bands. The I bands, labeled as light bands, contain only actin filaments and are located on either side of the Z discs. The A band, labeled as the dark band, is where myosin is present and overlaps with actin, with the H zone in the middle, containing only myosin. The cross-bridges, Titin filament, M line, and Z disc are all pointed out to show their arrangement within the sarcomere.

A section of TEM (transmission electron microscopy) is included to show the striations in muscle tissue, corresponding to the zones and bands in the diagram. Various other components such as the nucleus, capillary, sarcolemma (plasma membrane), sarcoplasmic reticulum, and mitochondrion are identified in their respective places within the muscle fibers.

[Generated by AI]

How a sarcomere contracts

The force achieved during muscle contraction is a result of the simultaneous contraction of all the sarcomeres in that muscle. The sliding filament theory explains the contraction of a sarcomere. According to this theory, when a muscle is stimulated to contract, actin filaments slide over the myosin filaments towards the centre of the sarcomere (**Figure 3**). This results in:

- Z discs being pulled closer together, shortening the sarcomere and resulting in the overall shortening of the muscle fibre
- The H bands and I bands decrease in length as actin is pulled inwards, overlapping more myosin and reducing the area where only myosin or actin is present.

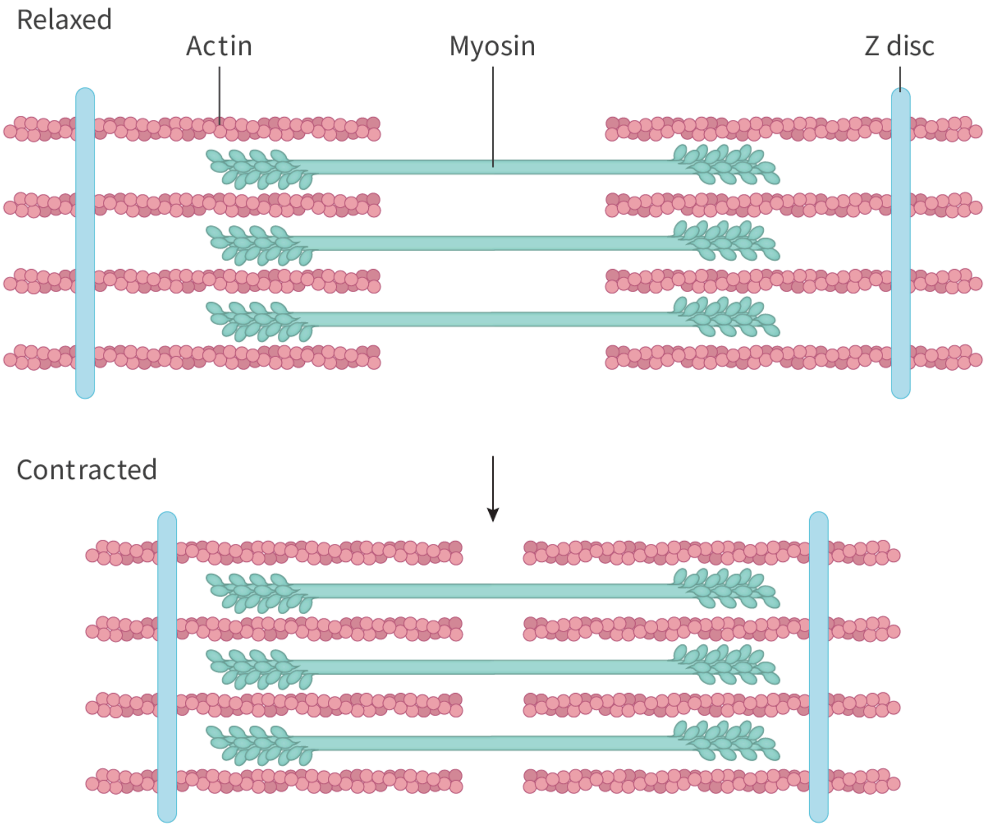

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Figure 3. Relaxed and contracted state of a sarcomere.

Source: "Human skeletal muscle tissue 2 - TEM (https://commons.wikimedia.org/wiki/File:Human_skeletal_muscle_tissue_2_-_TEM.jpg)" by Louisa Howard is in public domain

More information for figure 3

This diagram illustrates the relaxed and contracted states of a sarcomere, a structural unit of muscle tissue. The top part of the diagram shows the relaxed state, while the bottom part shows the contracted state. In both states, actin filaments are depicted as pink strands, and myosin filaments as green strands. The Z discs, shown in blue, are the boundaries of the sarcomere. In the relaxed state, the actin and myosin are more spread out, while in the contracted state, they are closer together, indicating muscle contraction. The labels indicate the positions of actin, myosin, and Z disc, demonstrating how the sarcomere shortens during contraction.

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Without electrical stimulation, the myosin binding sites on actin filaments are blocked by a thin and fibrous protein subunit called tropomyosin. Tropomyosin runs alongside the actin filament preventing the binding of myosin to actin and hence preventing contraction of the muscle.

Tropomyosin is associated with another protein subunit called troponin. When a muscle is stimulated by a motor neuron, calcium ions are released from the sarcoplasmic reticulum, a specialised endoplasmic reticulum that is found in the sarcoplasm (cytoplasm) of muscle cells. These calcium ions bind to troponin, causing it to undergo a conformational change (**Figure 4**). As a result of this conformational change, troponin moves tropomyosin away from the myosin binding sites, allowing myosin to bind to actin.

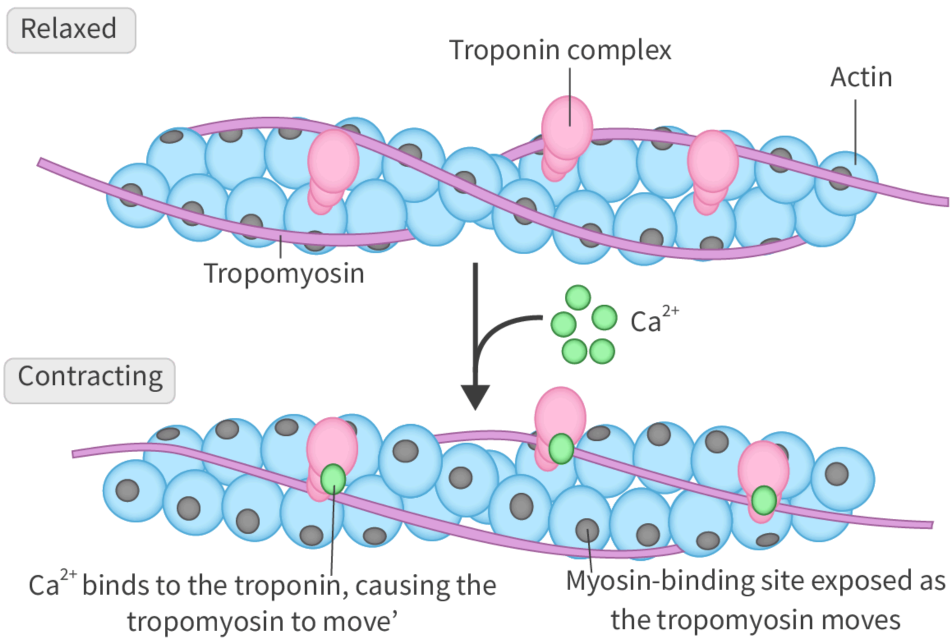

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Figure 4. The interaction of calcium ions, troponin and tropomyosin during muscle contraction.

More information for figure 4

The diagram illustrates the interaction of calcium ions, troponin, and tropomyosin during muscle contraction. It consists of two parts: the upper section labeled 'Relaxed' and the lower section labeled 'Contracting'.

In the 'Relaxed' state, the diagram shows actin filaments with troponin complexes and tropomyosin inhibiting the myosin-binding sites. The actin filament is depicted with tropomyosin wrapped around, blocking these sites, and troponin positioned on intervals along the filament.

In the 'Contracting' state, calcium ions (Ca2+) bind to the troponin complex, causing a conformational change. As a result, the diagram illustrates the movement of tropomyosin away from the myosin binding sites on the actin filaments. This exposes the myosin-binding sites, facilitating muscle contraction.

Arrows indicate the direction of change from the relaxed to the contracting states, emphasizing the role of calcium ions in triggering this transition.

[Generated by AI]

ATP is required in muscle contraction. It binds to the myosin head, causing it to detach from its binding site on an actin filament. ATP is hydrolysed into ADP and Pi and the myosin head changes position, moving towards the next myosin binding site on the actin filament. Once in this position, the myosin head attaches to the new binding site, forming a cross-bridge. The myosin head then returns to its original position, pulling the actin filament towards the centre of the sarcomere in a process called the power stroke. This cycle is repeated when another ATP molecule binds to the myosin head, allowing it to detach from the actin filament (**Figure 5**).

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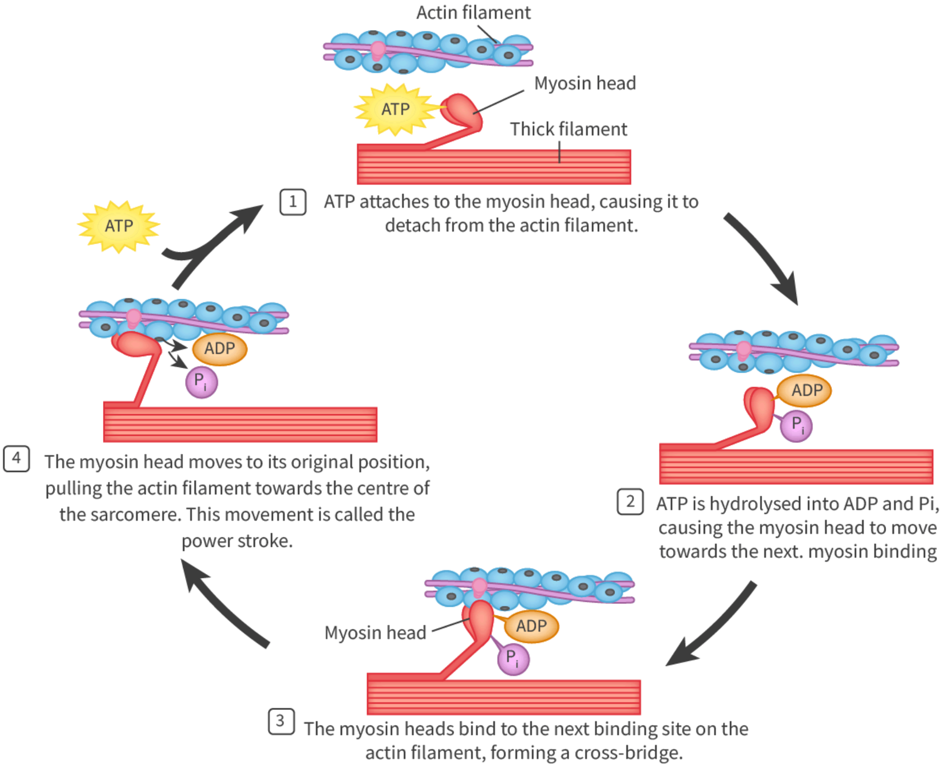

Figure 5. The steps involved in sarcomere contraction.

More information for figure 5

The image is a labeled diagram illustrating the sequence of events in sarcomere contraction across four main steps, each depicted in a separate section of the diagram.

1. The first step shows an ATP molecule attaching to a myosin head, causing it to detach from the actin filament. The labeled elements include the actin filament, myosin head, and thick filament.
2. In the second step, ATP is hydrolyzed into ADP and Pi, which shifts the myosin head towards the next actin binding site. This section highlights the new positions of ADP and Pi near the myosin head.
3. During the third step, the myosin head binds to the next myosin binding site on the actin filament, forming a cross-bridge.
4. The fourth step illustrates the myosin head moving back to its original position, pulling the actin filament towards the sarcomere center, in what is known as the power stroke. This repeats the contraction cycle with a new ATP molecule attaching to the myosin head.

Arrows indicate the sequence and direction of each step in the process, providing a clear flow of events in muscle contraction at the molecular level. Each part is labeled to guide the understanding of specific actions and molecular interactions.

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Watch **Video 1**, which shows the entire process below of muscle contraction.

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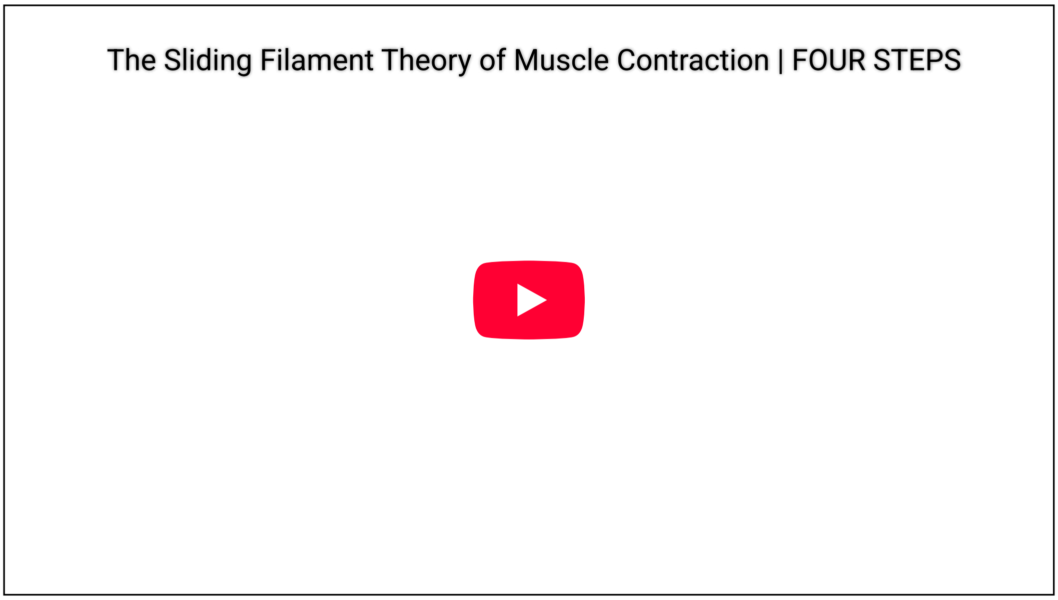

Video 1. Sliding filament theory.

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Acupuncture is a traditional Chinese medicine that has been used for thousands of years to treat a wide range of physical and mental health conditions, and is commonly used to treat many musculoskeletal conditions including back pain, arthritis and sports injuries.

Acupuncture is based on the belief that there are energy pathways in the body that can become blocked or disrupted. Acupuncture involves inserting thin needles into energy pathways in the body to restore the flow of energy and promote healing. Motor point acupuncture, for example, is a specific technique whereby acupuncture needles are inserted into areas where motor nerves enter the muscle tissue, with the aim of increasing blood flow to that area, reducing pain and inflammation.

The use of acupuncture has become increasingly popular in countries all around the world, reflecting a growing recognition of the potential benefits of holistic approaches to health and wellness, as well as highlighting the importance of exploring and learning from diverse perspectives on health and healing.

The role of titin in muscle relaxation

Titin is an immense (giant), elastic protein, one of the largest proteins known to science. Whereas the median human protein length is 375 amino acids, human titin is composed of over 34 000 amino acids. Titin is primarily found inside the sarcomeres of striated muscles, connecting the Z discs and the M lines and providing support and stability to the muscle fibres.

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Titin acts as a molecular spring. When a sarcomere is stretched, titin is also stretched, storing potential energy that is released when the stretching force is released. This release of energy helps to return the sarcomere to its original length, allowing the muscle to resume normal function.

Titin also acts like an elastic band providing passive resistance to prevent the overstretching of relaxed muscle. This elastic band-like property helps to maintain the structural integrity of the muscle and prevents it from becoming damaged due to excessive strain or stretching.

Find out more about titin here (https://pdb101.rcsb.org/motm/185).

The role of antagonistic muscles in muscle relaxation

When a muscle contracts, it shortens and pulls on its attachment points, causing movement of a bone or other body part.

A muscle can only contract and generate force in one direction. Because of this, some muscles are found in antagonistic pairs, such as the biceps and triceps (**Figure 6**). When one muscle in the antagonistic pair contracts, the other relaxes. For example, to bend the arm, the biceps contract and the triceps relax, and to extend (straighten) the arm, the triceps contract and the biceps relax.

The opposing action of antagonistic muscles allows for smooth, controlled movement of bones.

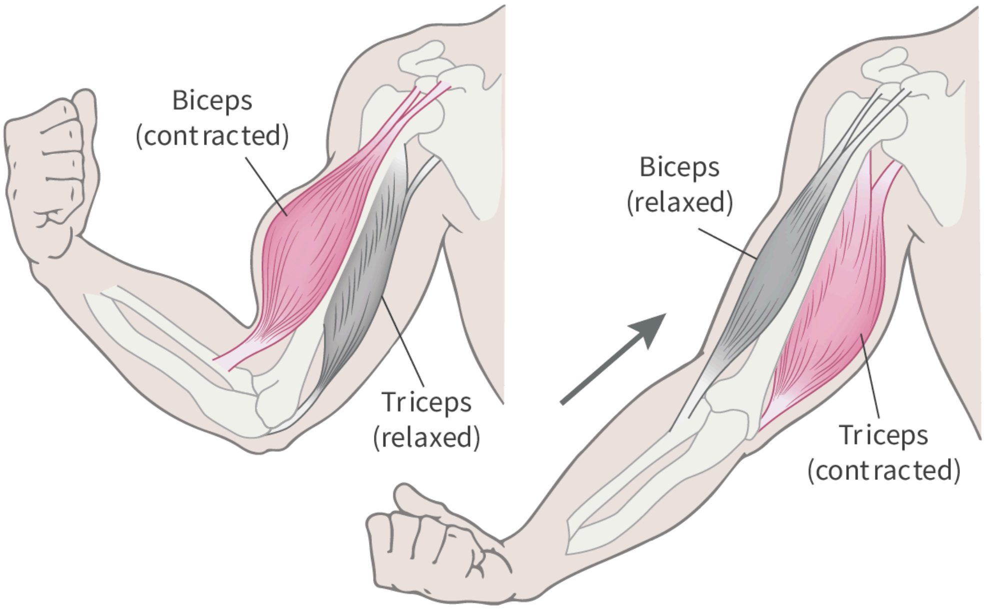

Figure 6. The biceps and triceps are an antagonistic muscle pair.

More information for figure 6

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Overview (/study/app/bio/sid-422-cid-755105/o

The diagram illustrates the relationship and function of the biceps and triceps as antagonistic muscles. On the left side, an arm is shown with the biceps contracted and the triceps relaxed. This configuration is depicted by the biceps being labeled and shaded in pink, while the triceps are shown in gray. On the right side, the same arm is shown a moment later, but now with the triceps contracted and the biceps relaxed. Here, the triceps are highlighted in pink, and the biceps are in gray. An arrow between the two images indicates the transition between these muscle states. This change demonstrates how the contraction and relaxation of these muscles facilitate the bending and straightening of the arm.

[Generated by AI]

Other examples of antagonistic muscle pairs include:

- the internal and external intercostal muscles, which work together to raise and lower the ribs to allow ventilation of the lungs (see section B3.1.5—6 (/study/app/bio/sid-422-cid-755105/book/ventilation-in-the-lungs-id-44439/) and later in this section)
- the quadriceps and hamstrings, which work together to produce movement at the knee joint, and
- the pectoralis major and latissimus dorsi, which work together to produce movement at the shoulder joint.

Skeletal muscle units

A skeletal muscle unit, also known as a motor unit, is a functional unit composed of a motor neuron and the muscle fibres that it innervates.

Muscle fibres are long, cylindrical structures that make up the skeletal muscle. A muscle fibre is composed of many myofibrils which contain sarcomeres, and it contains a specialised cytoplasm called the sarcoplasm (**Figure 7**). Surrounding myofibrils is the sarcoplasmic reticulum, a specialised form of endoplasmic reticulum which contains stores of calcium ions.

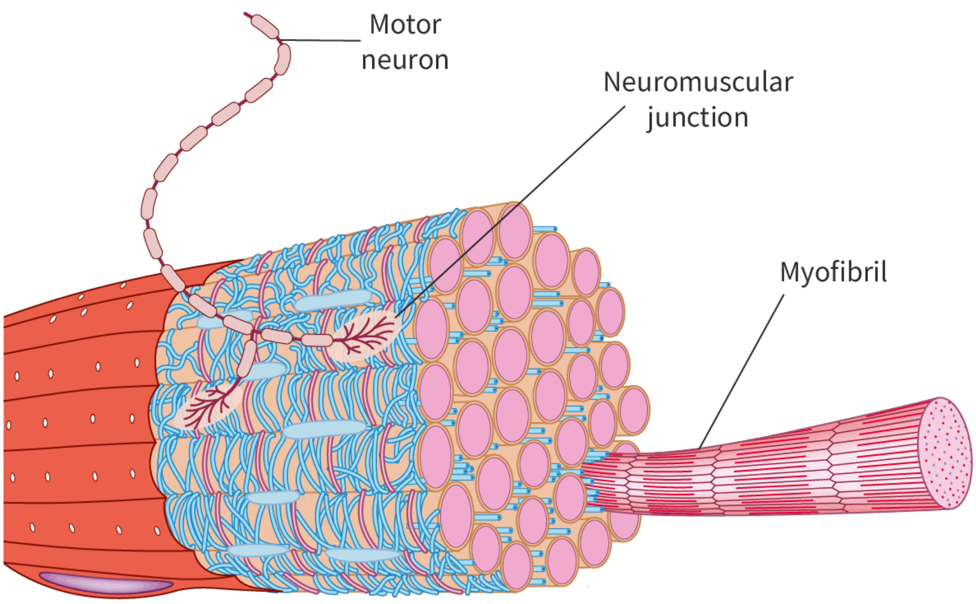

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Figure 7. A skeletal muscle unit.

More information for figure 7

The diagram illustrates a skeletal muscle unit, detailing the structural components of a muscle fiber. On the left, a motor neuron extends its axon towards the muscle fiber, ending at a neuromuscular junction where it meets the muscle cell. This synapse facilitates the transmission of signals from the nerve to the muscle, critical for muscle contraction.

The central part of the diagram depicts the muscle fiber's internal structure, densely packed with myofibrils. These myofibrils are cylindrical structures arranged in parallel and are the basic units of a muscle's contractile properties. The myofibrils are shown cut in a cross-sectional view, appearing as pink circles surrounded by blue filaments, symbolizing the sarcoplasmic reticulum network which stores calcium ions necessary for muscle contractions.

On the right, the myofibril extends outwards, detailed with striations that represent the sarcomeres — the repeating units that contract during muscle movement.

Lines with labels identify each of these components in the diagram, providing a guide to understand the relationship between the neural input from the motor neuron and the muscular output at the myofibrils.

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Motor neurons are nerve cells that transmit messages from the central nervous system to effector organs such as muscles or glands (see section C3.1.7 (/study/app/bio/sid-422-cid-755105/book/sensory-and-motor-neuronsome-id-44822/)). In the case of skeletal muscle, the axon terminal of a motor neuron connects to individual muscle fibres via a specialised synapse called the neuromuscular junction. This connection allows motor neurons to coordinate voluntary or involuntary actions, such as the pain reflex arc (see section C3.1.9 (/study/app/bio/sid-422-cid-755105/book/reflex-arcs-and-role-of-the-cerebellum-id-44823/)).

When an action potential travels down the motor neuron, the motor neuron releases a neurotransmitter called acetylcholine that diffuses across the synaptic cleft and binds to acetylcholine receptors on the motor end plate of the muscle fibres. This causes calcium ions to be released from the sarcoplasmic reticulum, triggering muscle contraction (**Figure 8**).

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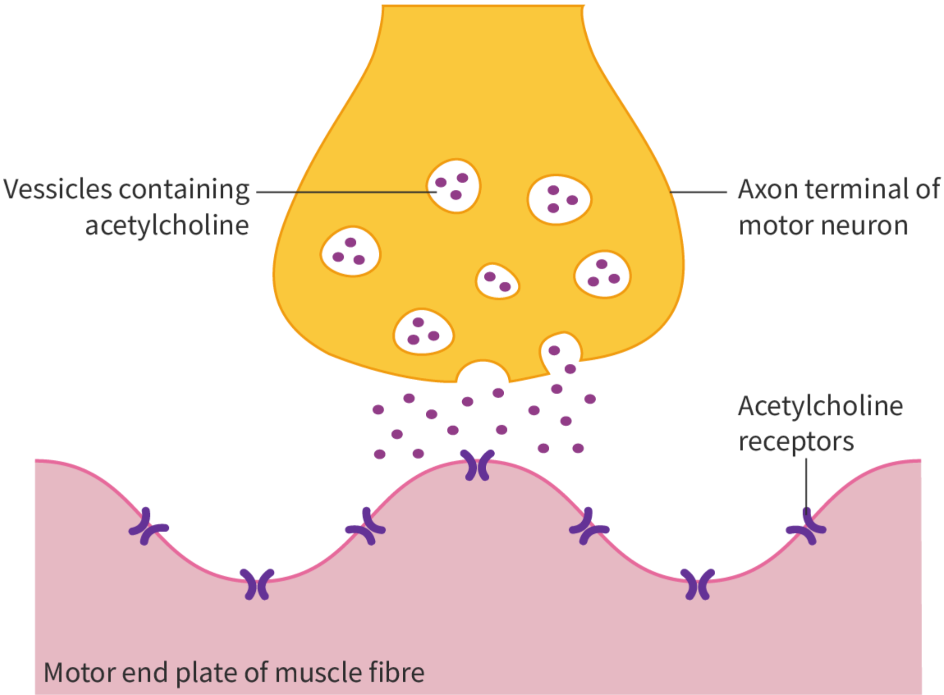

Figure 8. Neuromuscular junction.

More information for figure 8

The diagram illustrates the neuromuscular junction where a motor neuron interfaces with a muscle fiber. At the top, the axon terminal of the motor neuron is represented as a large yellow bulb. This terminal contains vesicles filled with acetylcholine, depicted as small purple circles. These vesicles release acetylcholine into the synaptic cleft, symbolized by purple dots moving downward.

Below the synaptic cleft is the motor end plate of the muscle fiber, shown as a pink surface. This surface is lined with acetylcholine receptors, visualized as small, purple, Y-shaped structures.

The flow of acetylcholine toward the receptors indicates the process of signal transmission that triggers muscle contraction. Labels identify key structures: "Vesicles containing acetylcholine," "Axon terminal of motor neuron," "Acetylcholine receptors," and "Motor end plate of muscle fibre."

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Now try the two activities below. Firstly, familiarise yourself with the vocabulary from this content by completing the matching activity. Then order the steps to show the steps involved in muscle contraction in the second activity.

Activity

- **IB learner profile attribute:** Thinker

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- **Approaches to learning:** Thinking skills — Reflecting at all stages of the assessment and learning cycle
- **Time required to complete activity:** 20 minutes
- **Activity type:** Individual activity

Task 1

Match the name of the structure to the description in **Interactive 1.**

Match the words and definitions

The basic contractile unit of a muscle, contains actin and myosin

A fibrous contractile protein, forms the thin protein filaments in a sarcomere

A fibrous contractile protein, forms the thick protein filaments in a sarcomere

Thread-like structures found in muscle fibres composed of repeating sarcomeres

Specialised endoplasmic reticulum that surrounds a myofibril and contains and releases calcium ions

The region on a sarcomere where myosin is present

The region on a sarcomere where only actin is present

A region in the middle of the sarcomere containing only myosin

Myosin | Sarcoplasmic reticulum | Actin | H band | I band | A band | Sarcomere | Myofibril

Check

Interactive 1. Match Up the Structure to the Correct Description.

Task 2

Order the steps below to describe the process of muscle contraction in **Interactive 2.**

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Complete the missing steps

1. An electrical message is sent from the brain via a motor neuron
2.
3.
4. Acetylcholine diffuses across the synaptic cleft
5.
6.
7. Calcium ions bind to troponin, altering its conformation
8.
9.
10. Myosin head binds to a new binding site, forming a cross-bridge
11.
12.

- ATP binds to the myosin head and is hydrolysed, causing the myosin head to detach from its binding site on the actin filament and move upwards
- Acetylcholine is released from the axon terminal of the motor neuron
- Calcium ions are released from the sarcoplasmic reticulum
- Troponin moves tropomyosin away from the myosin binding sites on the actin filament
- The release of ADP and Pi causes the myosin head to change position, pulling the actin filament towards the centre of the sarcomere in a process known as the power stroke
- This cycle of cross-bridges forming and a power stroke being executed is repeated when another ATP binds to the myosin head, resulting in the actin filaments being pulled in towards the M line, shortening the sarcomere
- Acetylcholine binds to acetylcholine receptors on the motor end plate of the muscle fibre
- The electrical message reaches the axon terminal of the motor neuron

Check

Student view

Interactive 2. Order the Steps to Outline the Processes Leading to Muscle Contraction.

B3. Form and function: Organisms / B3.3 Muscle and motility (HL)

Bones and joints (HL)

B3.3.5: Roles of skeletons as anchorage for muscles and as levers (HL) B3.3.6: Movement at a synovial joint (HL)
B3.3.7: Range of motion of a joint (HL)

Higher level (HL)

Learning outcomes

By the end of this section you should be able to:

- Outline the role of the skeleton as anchorage for muscles and as levers.
- Explain the role of the different components of a joint.
- Compare the range of motion of a joint.

The adult human body has 206 bones. These bones provide support and protection for your internal organs, produce blood cells and enable movement of your body parts. But how do bones and muscles work together to enable movement? How is one bone able to move while others are static? Are all animals equipped with an internal skeleton?

Roles of skeletons as anchorage for muscles and as levers

A skeleton is a structural framework composed of bone and other connective tissue that provides support, shape and protection for an organism's body. Although skeletons are unable to move by themselves, they act as anchorage points for muscles, and because of their rigidity, the bones in a skeleton act as levers.

Levers are rigid structures that act around a fulcrum in response to an applied force. In this context, the bone acts as the lever, the joint as the fulcrum and the force is generated by the contraction of a muscle that is attached to the bone.

There are two types of skeletal systems found in animals, endoskeletons and exoskeletons.

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Arthropods are a diverse group of organisms that are characterised by jointed legs, segmented bodies and tough exoskeletons made of the complex polysaccharide chitin. The exoskeleton acts as a type of external armour to protect the soft body parts inside from physical damage and dehydration (**Figure 1**). Because the exoskeleton is located outside the body, it must be periodically shed and replaced as the animal grows. The exoskeleton acts as an attachment site for muscles. When the muscles contract, they pull on the tendons which in turn pull on the exoskeleton and produce movement.

Figure 1. A grasshopper shedding its exoskeleton.

Credit: Cathy Keifer, Getty Images (https://www.gettyimages.co.uk/detail/photo/grasshopper-shedding-royalty-free-image/118324525)

Vertebrates, animals with a backbone (spinal column), have an endoskeleton, an internal structure made of bone and cartilage. The endoskeleton provides support and protection for the body's internal organs, and acts as anchorage sites for muscles. Muscles contract to generate the force necessary to move the bone they are attached to and allow movement of the body.

Movement at a synovial joint

Joints are the articulating surfaces between two or more bones. Synovial joints are joints that are enclosed in a joint capsule, where bones are separated by a fluid-filled cavity, allowing free movement between the bones.

Within the cavity is synovial fluid, which acts as a lubricant to reduce friction between bones. Articular cartilage covers the end of the bones in a synovial joint, acting as a cushion to absorb shock. Cartilage has a smooth surface, which helps to facilitate the

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smooth movement of bones over each other.

The bones in a synovial joint are connected by ligaments. Ligaments are strong, flexible bands of connective tissue that provide stability to the joint and prevent excess movement or dislocation of the joint.

The force required to move a bone in a joint is generated by muscles, which are attached to bones via tendons, strong fibrous bands of connective tissue. When a muscle contracts, it exerts a pulling force on the tendon, and hence on the bone, which causes the movement of that bone relative to the rest of the joint.

Ligaments, tendons and cartilage all contain collagen. Because of its fibrous structure (see section B1.2.11–13 (/study/app/bio/sid-422-cid-755105/book/membrane-fluidity-hl-id-44646/)), collagen is rigid and relatively resistant to stretching.

The hip joint is a synovial joint that connects the femur bone in the thigh to the pelvis bone (**Figure 2**). It is a ball and socket joint – the rounded head of the femur fits into the cup-like socket of the pelvis.

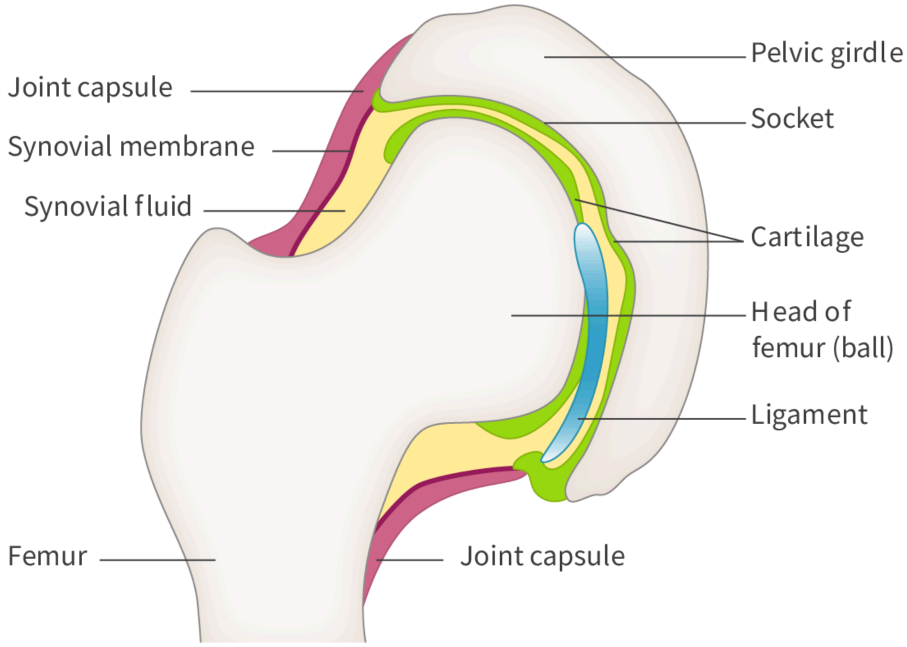

Figure 2. The hip joint allows your leg to flex, extend, rotate and swing side to side.

More information for figure 2

This diagram illustrates the anatomy of the hip joint, a synovial joint connecting the femur to the pelvis. The image labels key components: the femur (thigh bone), pelvic girdle (part of the pelvis), socket (acetabulum of the pelvis where the femur head fits), head of femur (known as the ball), joint capsule (a fibrous cover enclosing the joint), ligaments (band-like tissues stabilizing the joint), the synovial membrane (lining within the joint capsule), synovial fluid (fluid for lubrication), and cartilage (smooth tissue covering the femur head and socket to allow smooth movement).

[Generated by AI]

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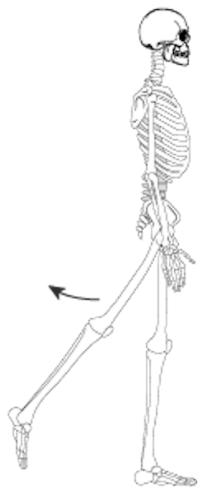
The structure of the hip joint allows for a wide range of movement, including flexion, extension, abduction, adduction, rotation and circumduction (**Table 1**).

Table 1. Different types of movement of the hip.

Type of movement at a synovial joint	Description	Example involving the hip	Image
Flexion	Bending of a joint that decreases the angle between the bones involved	Bringing your knee closer to your chest	
Extension	Straightening of a joint that increases the angle between the bones involved	Moving the thigh away from the chest	

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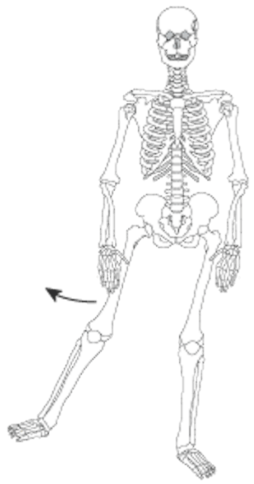
Type of movement at a synovial joint	Description	Example involving the hip	Image
Abduction	Movement of a bone away from the midline of the body	Pushing your knees apart	 More information The image is a diagram of a human skeleton. It shows a full-body view of the skeleton including the skull, spine, ribcage, arms, pelvis, and legs. The skeleton's right leg is slightly raised, and an arrow points to it, possibly indicating a focus on that area. The major bones are depicted, such as the femur, tibia, and fibula in the legs, the humerus, ulna, and radius in the arms, and individual rib bones connecting to the sternum. The pelvis and shoulder joints are also visible. Various joints are represented, showing the connections between bones. This diagram is used for anatomical study and understanding of the skeletal structure and its components. [Generated by AI]

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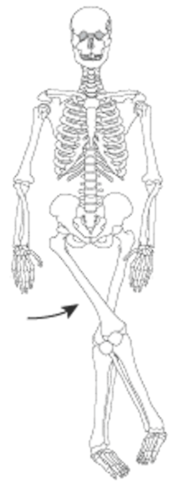
Type of movement at a synovial joint	Description	Example involving the hip	Image
Adduction	Movement of a bone towards the midline of the body	Pushing your knees in together	

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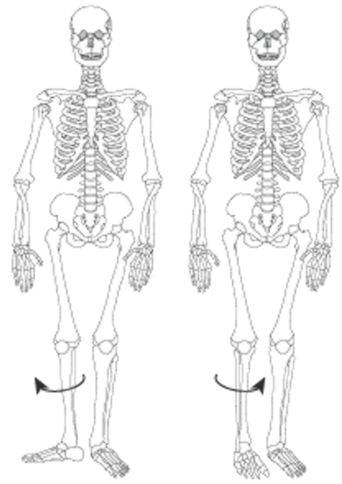
Type of movement at a synovial joint	Description	Example involving the hip	Image
Rotation	Movement of a bone around its axis	Turning the leg inward or outward while keeping the knee and foot in the same position.	 More information The image is an illustration depicting two human skeletons side by side. Both skeletons are standing upright; however, the one on the left has its feet placed at different angles compared to the one on the right, which might suggest a difference in stance or posture. The illustration shows all major bones including the skull, rib cage, pelvis, and limbs, providing a clear comparison between the two skeletal structures. [Generated by AI]
Circumduction	Circular movement of a limb that involves flexion, abduction, extension, and adduction in sequence	Standing up and tracing a circle with a straight leg	

The knee, elbow and shoulder joints are other examples of synovial joints.

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Range of motion of a joint

The range of motion (ROM) in a joint refers to the type and amount of movement that is possible at that joint. Joints with a high ROM allow for a wider range of movement and often multiple planes of motion, allowing for greater flexibility and mobility. The hip and elbow joints are examples of joints with a high ROM. Joints with a low ROM allow for limited movement, or no movement at all, such as the sutures in the skull or the vertebrae in the spine.

ROM is determined by the joint's anatomical structure, the surrounding muscles, ligaments, tendons and the presence of other tissue that can facilitate or limit movement. The ROM of a joint can vary between individuals, and can be affected by injury, disease or ageing. Stretching, regular exercise and physiotherapy are all ways to help improve and maintain the ROM of joints.

To measure the amount of movement of a joint, the joint angle is measured. This is the angle at which a bone can move relative to its resting position; a manual instrument called goniometer can be used. **Video 1** shows you how to use a goniometer.

Video 1. How to Use a Goniometer.

More information for video 1

An interactive video demonstrates how to use a goniometer. In the video, a medical professional wearing a white coat and a stethoscope performs a goniometer assessment on
a patient who is seated beside a table with the hand resting on it.

The goniometer is a plastic tool resembling a protractor with two long arms. Both the arms and the protractor have measurement scales. One arm is stationary, while the other is movable to measure joint angles.

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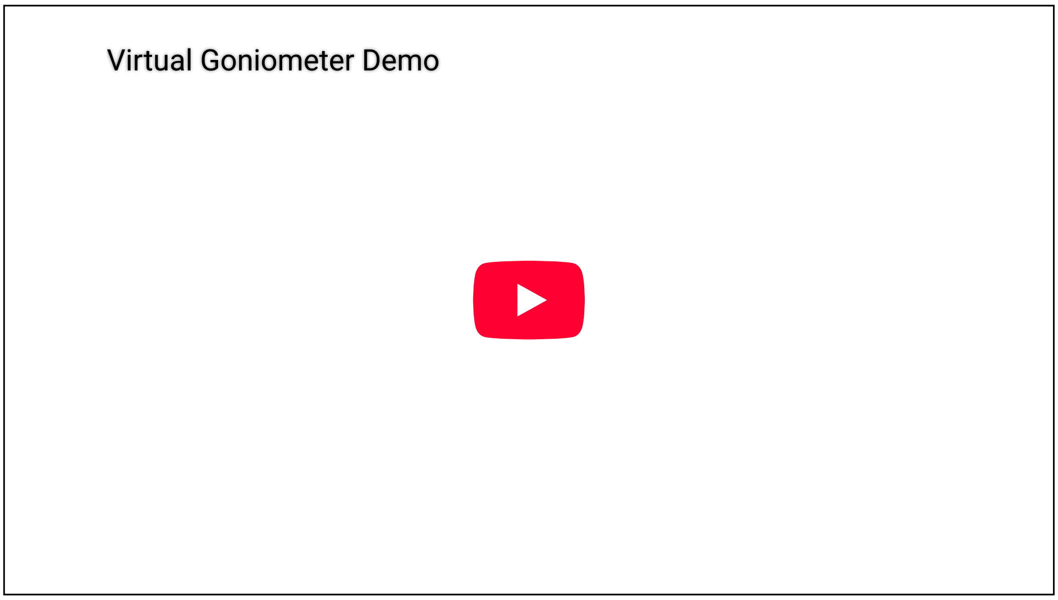
The medical professional measures the wrist joint angles of the patient. The center of the goniometer is placed at the wrist joint, with the patient’s palm elevated. The forearm aligns with the stationary arm of the goniometer, and the elevated palm aligns with the movable arm.

As the video progresses, the medical professional moves the movable arm upward, and the patient’s palm follows in the same direction until the wrist reaches its extension limit. Then, the arm is moved downward, with the patient’s palm bending accordingly.

As the video continues, the medical professional places the goniometer flat on the table. The patient’s hand is also laid flat on the table.

This video helps users understand how to properly align and use a goniometer to measure wrist joint angles.

Computer analysis, such as the virtual goniometer in **Video 2** can also be used to measure joint angles. In contrast to an analogue goniometer, computer analysis tends to be able to measure joint angles faster and in multiple planes of movement, providing a more complete picture of joint function.



Video 2. A virtual goniometer.

More information for video 2

The video demonstrates the use of motion sensors, to track joint angles in real-time across multiple planes. It displays real-time angle data with blue lines for joint tracking. This is helpful in providing instant calculations, reducing human error and a dynamic analysis.
The video shows a model sitting on a chair. The top left corner of the video shows the “Recorded angles” set at 65 degrees (115 degrees). The paired values suggest measuring both flexion and extension. When she raises and folds her left arm, the virtual tool measures the angle using a blue line. The recorded angle reads 41 degrees (139 degrees). When she extends her arm, the blue line again measures the angle which is recorded as 91 degrees (89 degrees).
The model then shifts the position of the camera to focus on her legs. She moves her left lower leg away from the body (abduction) and the line measures and records the angles 36 degree (144 degree). She then moves the same leg towards her body (adduction) and the line measures and records the angles 28 degrees (152 degrees).

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The model turns left presenting her right side and readjusts the focus of the camera. She lifts her right leg straight up and the line measures and records the angles 179 degrees (1 degree). She then folds her leg down and the line measures and records the angles 67 degree (113 degree).
Virtual goniometry revolutionizes ROM analysis with precision and efficiency, enhancing clinical workflows.

Nature of Science

Aspect: Measurements

The use of technology enables scientists to measure data in novel ways, expanding the scope and depth of scientific enquiry. The use of a goniometer relies on the skill and experience of the practitioner, and small errors in measurements can lead to inaccurate results. However, the use of computer analysis to determine joint angles enables doctors and health professionals to diagnose and treat patients with a wide range of musculoskeletal conditions more accurately and effectively.

You might also use a protractor to measure joint angles using images of joint movement, as shown in Worked example 1.

Worked example 1

The image below shows movement of the tibia in the lower leg relative to the femur in the upper leg.

Measure the joint angles shown in **Figure 3**, and describe the type of movement shown.

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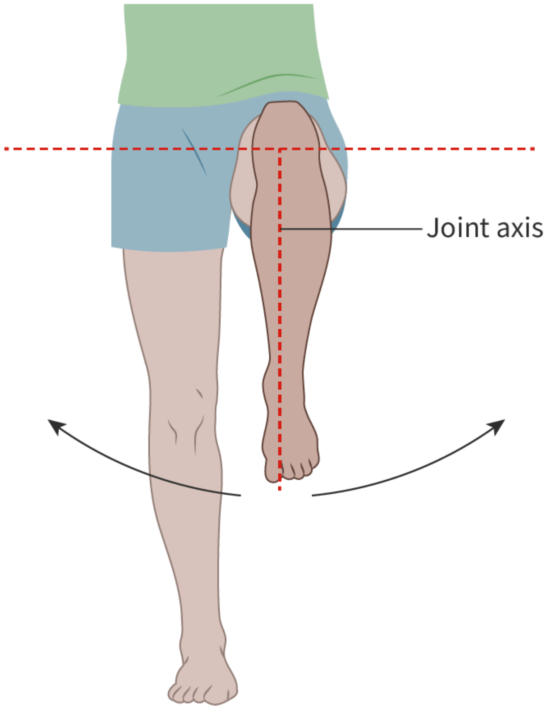

Figure 3. Joint angle exercise.

More information for figure 3

The image is an illustration of a person performing a joint angle exercise, demonstrating a specific movement of the leg. The person is wearing shorts and a t-shirt. The illustration outlines the joint axis with a red dashed line running vertically through the body and another horizontal dashed line at the knee level. Black arrows indicate the range of motion of the leg, suggesting an exercise focused on the knee joint. The text "Joint axis" points to the axis around which the leg is moving, illustrating the concept of joint angles in physical exercises.

[Generated by AI]

The joint axis is an imaginary line that runs through the centre of a joint. Line your protractor up with the joint axis and measure the largest angle created by movement of a bone in a particular direction.

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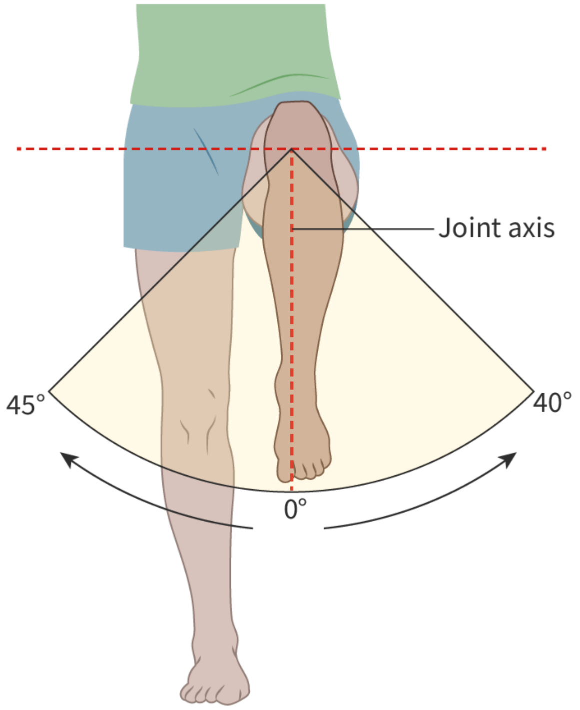

The individual in the diagram can move their left lower leg 40 degrees to their left, and 45 degrees to their right.

The diagrams show movement of a bone on its axis, a type of movement called rotation.

Try the activity below to label and describe the elbow joint in Task 1. In Task 2, identify the type of movement shown and measure the joint angles.

Activity

- **IB learner profile attribute:**
    - Thinker
    - Inquirer
- **Approaches to learning:**
    - Thinking skills — Reflecting at all stages of the assessment and learning cycle
    - Research skills — RS.4 Comparing, contrasting and validating information
- **Time required to complete activity:** 25 minutes
- **Activity type:** Individual activity

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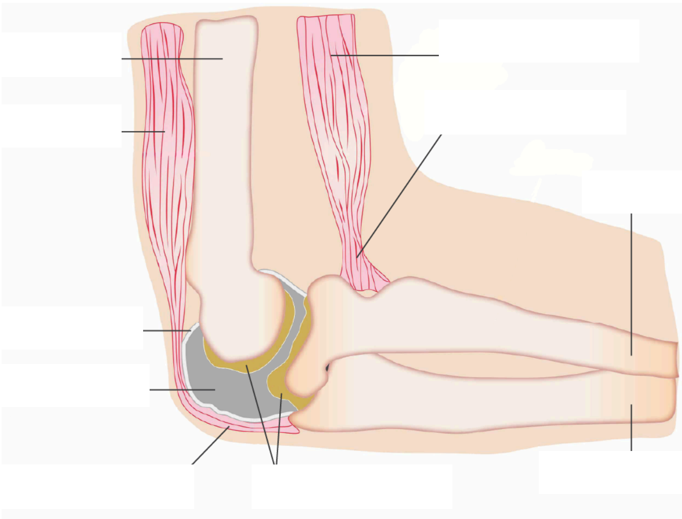
Task 1

The elbow joint is a synovial joint that functions to extend (straighten) and flex (bend) the arm. Drag and drop the labels to the correct place on the elbow. Once you have done this, write a paragraph to explain the function of these different joint components.



Cartilage | Radius | Synovial fluid
Tendon of bicep | Tricep | Ulna | Joint capsule
Humerus | Tendon of tricep | Bicep

Check

Interactive 1. Drag and Drop the Labels to the Correct Location on the Elbow.

More information for interactive 1

This is a drag and drop interactive of a simplified side view of an arm bent to the elbow. It illustrates the basic skeletal and muscular structure around an elbow joint.
Two long, pale tan shapes represent the upper and lower arm bones, meeting at a curved joint. The upper arm bone extends from the top left, angling slightly downwards towards the elbow. The lower arm bone extends from the elbow towards the bottom right.
At the elbow joint, the ends of the bones are covered by smooth, light yellow caps, suggesting cartilage. A curved, greyish shape sits beneath the joint, representing a fluid around the joint.

Several bands of pink tissue, representing muscles or tendons, are attached to the upper and lower arm bones. On the upper arm, one thick pink band extends from the top left downwards and attaches to the front of the elbow joint. Another, thinner pink band is shown at the back of the upper arm, also attaching near the elbow.
On the lower arm, a thick pink band originates from the front of the elbow joint and extends

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downwards towards the bottom left. Another thick pink band originates from the back of the elbow joint and extends downwards towards the bottom right, along the back of the lower arm bone.

This drag and drop interactivity has a total of ten blanks marking different regions in the image. The ten options given at the bottom of the page are as follows: Cartilage, Radius, Synovial fluid, Tendon of bicep, Tricep, Ulna, Joint capsule, Humerus, Tendon of tricep, and last one is Bicep.

Read below for the solution:
The correct options in clockwise order: Bicep, Tendon of bicep, Radius, Ulna, Cartilage, Tendon of tricep, Synovial fluid, Joint capsule, Tricep, and at the end Humerus.

Interactive 1. Drag and drop the labels to the correct location on the elbow.

Task 2

Now have a go at measuring the joint angles and identifying the types of movement shown in the interactives below. Remember to refer back to **Worked example 1** if you need some guidance.

Interactive 2. Measure the joint angles and identify the types of movement.

More information for interactive 2

This interactive activity is designed to help users identify different types of hip joint movements and measure the angles formed at the joint. It serves as an educational tool for students, healthcare professionals, and individuals interested in anatomy, physiotherapy, sports science, and biomechanics.

The activity consists of four static images, each depicting a leg in a different position to demonstrate various types of movement at the hip joint. The user must complete two tasks for each image:

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1. Identify the Type of Movement:
   Each image represents a specific movement of the hip joint. Users must analyze the position of the leg and select the correct movement type from a dropdown menu. The movement could be one of the following:
   - Flexion: The leg moves forward, decreasing the angle between the femur and pelvis.
   - Extension: The leg moves backward, increasing the angle between the femur and pelvis.
   - Abduction: The leg moves outward, away from the body's midline.
   - Adduction: The leg moves inward, toward the body's midline.
   - Rotation: The femur turns around its long axis (internal or external rotation).
   - Combination Movements: Some positions involve a mix of flexion-extension and abduction-adduction.
2. Measure the Angle of the Joint:
   A draggable protractor tool is provided to measure the hip joint angle. Users must drag and align the protractor with the leg's position to determine the exact angle at the hip joint. The measured angle is then entered into a corresponding text box.
   By completing this activity, users develop a deeper understanding of how the hip joint moves and how to measure its range of motion accurately, a skill crucial for health professionals and sports scientists.

5 section questions

B3. Form and function: Organisms / B3.3 Muscle and motility (HL)

The intercostal muscles (HL)

B3.3.8: Internal and external intercostal muscles (HL)

Section Student... (0/0) Feedback Print (/study/app/bio/sid-422-cid-755105/book/the-intercostal-muscles-hl-id-44817/print/) Assign

Higher level (HL)

Learning outcomes

By the end of this section you should be able to explain the antagonistic action of the internal and external intercostal muscles.

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Place your hands around your rib cage and take a deep breath. As you inhale and exhale, you will feel your rib cage raise and lower, altering the size of your thoracic cavity, which results in the movement of air into and out of your lungs. What are the muscles found between your ribs? And how do they work together to facilitate movement?

The intercostal muscles are a group of muscles located between the ribs and the thoracic cavity that are involved in breathing (see section B3.1.5–6 (/study/app/bio/sid-422-cid-755105/book/ventilation-in-the-lungs-id-44439/)). There are two main groups of intercostal muscles:

1. The external intercostal muscles are the most superficial (closest to the surface of the body). They run in a downward and forward direction, diagonally towards the centre of the chest. When they contract the rib cage is lifted up and out.
2. The internal intercostal muscles are deeper and run in an upward and forward direction towards the centre of the chest, perpendicular to the external intercostal muscles. When they relax the rib cage moves down and in. When forced exhalation occurs, they contract.

There is also a third layer, called the innermost intercostal muscles, which are responsible for assisting in forced expiration during heavy breathing (**Figure 1**).

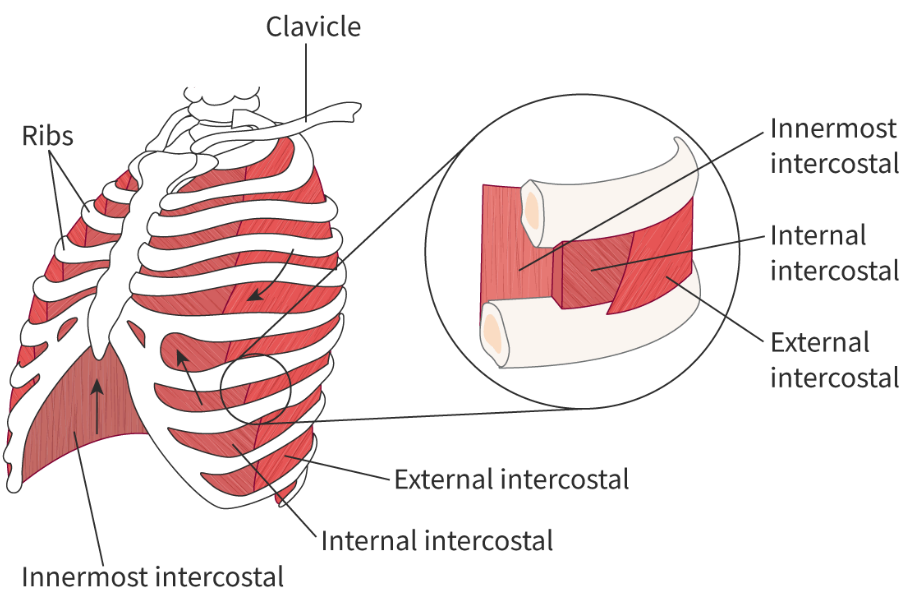

Figure 1. The internal and external intercostal muscles.

More information for figure 1

This diagram illustrates the rib cage with a focus on the intercostal muscles. On the left, a skeletal outline shows the ribs, clavicle, and associated muscles. Each layer of muscle is labeled: the external intercostal muscles are on the outermost layer, the internal intercostal muscles are deeper, and the innermost intercostal muscles are closest to the internal organs. Arrows denote the direction of muscle fibers and force applied during breathing.

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On the right, an enlarged, cross-sectional view highlights the specific arrangement of these muscles between two ribs. This view provides a clearer distinction between the three muscle layers, emphasizing their roles identified in the surrounding text.

[Generated by AI]

Because of the different orientation of muscle fibres in the internal and external layers of intercostal muscles, when they contract they move the rib cage in opposite directions. When one layer contracts, the other layer is stretched, storing potential energy in the sarcomere protein titin. When contraction of sarcomeres ends, the release of the potential energy stored in titin helps to return the sarcomere to its original length, allowing the muscle to resume normal function.

Watch **Video 1** for an explanation of how the intercostal muscles work.

Video 1. The location of the intercostal muscles and an explanation of how they move the ribcage.

Nature of Science

Aspect: Models

Models allow us to simplify complex systems, identify patterns and trends and make predictions about how a system will behave. Models are an essential component in understanding muscles and movement, but it is important to be aware that models are simplifications of reality and may not capture the

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complexity of the system being studied. As such, models should be continually evaluated and modified to ensure their validity and usefulness in furthering scientific understanding.

Try the activity below to make a model of the intercostal muscles.

Activity

- **IB learner profile attribute:** Thinker
- **Approaches to learning:** Thinking skills — Applying key ideas and facts in new contexts
- **Time required to complete activity:** 20 minutes
- **Activity type:** Individual activity

For this activity you will need:

- 6 split pins
- 2 strips of cardboard approximately 2 cm × 10 cm
- 3 strips of cardboard approximately 1 cm × 5 cm
- two different colours of small elastic bands
- a stapler and staples.

Use this equipment to make a model to show how the internal and external intercostal muscles are positioned and how they function. One of the larger strips of cardboard will represent the sternum, and one will represent the spine. The remaining three smaller pieces will represent ribs, attaching from the spine to the sternum. Use split pins to attach the bones, ensuring that they are able to move.

Choose one colour of elastic to represent the external intercostal muscles and position them closer to the spine, running diagonally down towards the sternum. Staple them onto the ribs. The other colour will represent the internal intercostal muscles and should be stapled closer to the sternum, running diagonally up towards the spine.

When you pull on the 'external intercostal muscles' the rib cage should move up relative to the spine, and when you pull the 'internal intercostal muscles' the rib cage should move down relative to the spine.

You might find the following webpages useful to support you in this activity:

https://www.yorku.ca/earmstro/journey/external.html
(https://www.yorku.ca/earmstro/journey/external.html)

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https://www.yorku.ca/earmstro/journey/internal.html (https://www.yorku.ca/earmstro/journey/internal.html)

5 section questions

B3. Form and function: Organisms / B3.3 Muscle and motility (HL)

Reasons for locomotion in animals and adaptations for swimming in marine mammals (HL)

B3.3.9: Reasons for locomotion (HL) B3.3.10: Adaptations for swimming in marine mammals (HL)

Section Student... (0/0) Feedback Print (/study/app/bio/sid-422-cid-755105/book/reasons-for-locomotion-in-animals-and-hl-id-44818/print/) Assign

Higher level (HL)

Learning outcomes

By the end of this section you should be able to:

- Give examples of reasons for locomotion.
- Describe adaptations for swimming in marine mammals.

Reasons for locomotion

Locomotion is the ability of an organism to move its whole body from one place to another – motile organisms can locomote but sessile organisms cannot. But why is locomotion necessary for some organisms?

Foraging for food

Foraging is the act of searching for and collecting food. Foraging behaviour can take many forms:

- some animals may graze on vegetation
- some may search for fruits, nuts and other plant-based food
- some animals may actively hunt and capture prey and
- some may scavenge for food that has already been killed and discarded.

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In the wild, horses (*Equus caballus)* will forage for around 16 hours per day, feeding on grass, herbs and other vegetation. In the wild, horses will cover large distances each day in search of fresh vegetation, spending several minutes in one spot and then moving on to the next spot (**Figure 1**). Domesticated horses that are confined to small spaces may exhibit repetitive movements or stress behaviours. An example is crib biting – grabbing and pulling objects with their teeth when they are unable to engage with natural foraging activities.

Figure 1. Horses forage for up to 16 hours per day in the wild.

Credit: panaramka, Getty Images

Bees (genus *Apis*), are insects that forage for nectar, pollen and water to bring back to their hive to feed their colony and raise their young. When foraging, bees usually fly from flower to flower, collecting nectar and pollen with their specialised mouthpieces and body hairs.

Bees rely on their sense of sight and smell to locate brightly coloured and scented flowers (**Figure 2**). They can also communicate to other bees using pheromones and a complex dance that communicates the location of the resources to other bees in the hive.

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view

Figure 2. Bees forage for nectar, pollen and water.

Credit: Capelle.r, Getty Images

Escaping from danger

Escape behaviours are usually fast and robust, enabling the animal to swiftly avoid threats such as predators or other hazards in their surroundings.

Elephants (genus *Loxodonta*) have been known to detect the infrasonic sounds of tsunamis before the tsunami hits the coast. In response, the elephants flee to the safety of higher grounds.

Animals use various types of locomotion to avoid their predators, depending on their physical abilities and environmental conditions. Common ways to avoid predators include running, jumping, flying, climbing and swimming. **Video 1** shows marine iguanas (*Amblyrhynchus cristatus*) escaping predation from racer snakes (*Pseudalsophis biserialis*).

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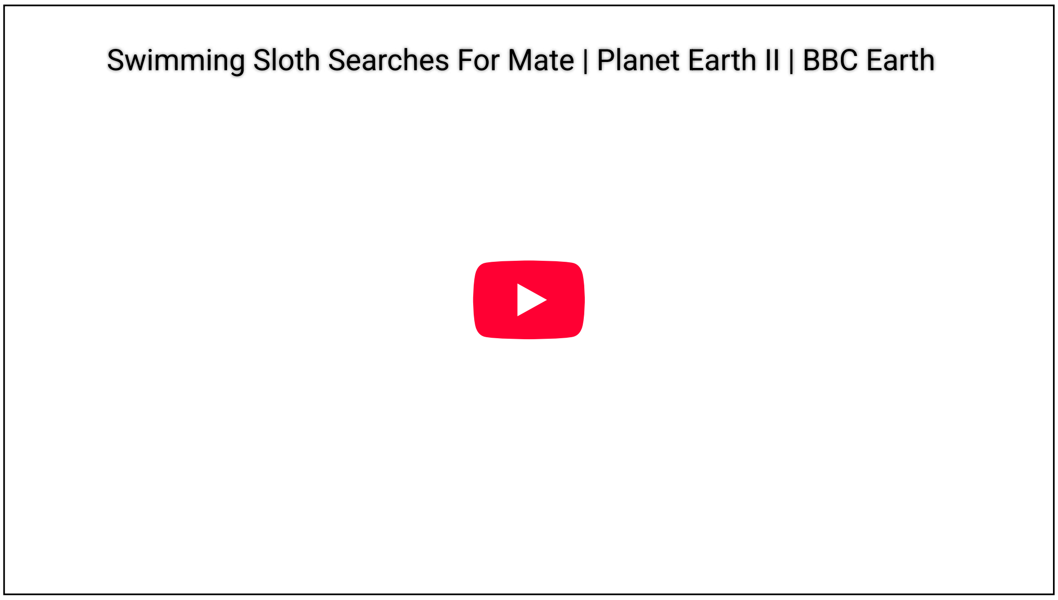
Video 1. Iguanas escaping predation.

Searching for a mate

Most animals reproduce sexually, which requires the fusion of male and female gametes. Because of this, most animals will need to move to a location where members of the opposite sex will be present. The more they can move, the more likely they are to find a suitable partner.

Some species have low population densities, which is particularly true for large territorial animals such as tigers. Tigers may have limited opportunity to interact with members of the opposite sex within their own territory, particularly as habitat destruction and poaching threaten the population size. Tigers commonly traverse huge distances in search of a mate, as reported in this BBC article (https://www.bbc.com/news/world-asia-india-50626744).

Organisms that reproduce sexually need to locomote to find a mate. Sloths, known for their slow, deliberate movements emit vocalisations to alert and attract potential mates of their whereabouts. **Video 2** shows a pygmy three-toed sloth (*Bradypus pygmaeus*) swimming between mangroves in search of a mate.



Video 2. A swimming sloth searching for a mate.

More information for video 2

1
00:00:00,080 --> 00:00:01,600
[soft music plays]
2
00:00:29,800 --> 00:00:31,640
narrator: Could this be her?
3

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00:00:38,360 --> 00:00:42,120
He does his best to put on
a turn of speed.
4
00:00:52,600 --> 00:00:54,120
But she's not the one.
5
00:00:54,640 --> 00:00:58,160
She already has a baby,
and she won't mate again
6
00:00:58,240 --> 00:01:01,280
until it leaves her
in about six months time.
7
00:01:08,400 --> 00:01:13,320
Even life on a Paradise Island
can have its limitations,
8
00:01:13,480 --> 00:01:15,000
[sound of river flowing]
9
00:01:15,840 --> 00:01:17,840
[sloth sound]
10
00:01:18,800 --> 00:01:21,360
but at least she can't be far away.
11
00:01:22,000 --> 00:01:23,440
[music fades out]

Migration

Migration refers to the large-scale seasonal movement of an animal group from one place to another. Migration occurs in all major animal groups, including birds, mammals, insects, crustaceans, fish, reptiles and amphibians

Emperor penguins, *Aptenodytes forsteri*, are the tallest and heaviest of all penguins. These flightless birds live on the Antarctic ice and migrate inland to their breeding grounds in early March, which is autumn in the southern hemisphere. Once an egg has been laid, the female parent journeys back to the ocean to feed, while the male parent stays to incubate the egg. Females return in August shortly after the chicks have hatched, taking over the parental care duties while the males journey back to the oceans to feed. Watch **Video 3** to learn about the migration of these penguins.

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Video 3. Migration of emperor penguins.

Find out more about emperor penguins here (https://www.nationalgeographic.com/animals/birds/facts/emperor-penguin).

The great white shark, *Carcharodon carcharias* is an endangered species found in coastal and offshore waters of all major oceans (**Figure 3**). They are a migratory species, alternating between breeding and foraging grounds. Researchers often capture, tag and release great white sharks to monitor their location and migratory behaviour.

A recent study in New Zealand found that male sharks migrate between Stewart Island, off the coast of New Zealand's South Island, where food is plentiful, to more northern tropical waters in the winter, as far as 3300 km away. Find out more about this study here (https://niwa.co.nz/oceans/research-projects/white-sharks).

You can also watch the real time movements of tagged ocean animals using the OCEARCH (https://www.ocearch.org/tracker/?list=) shark tracker.

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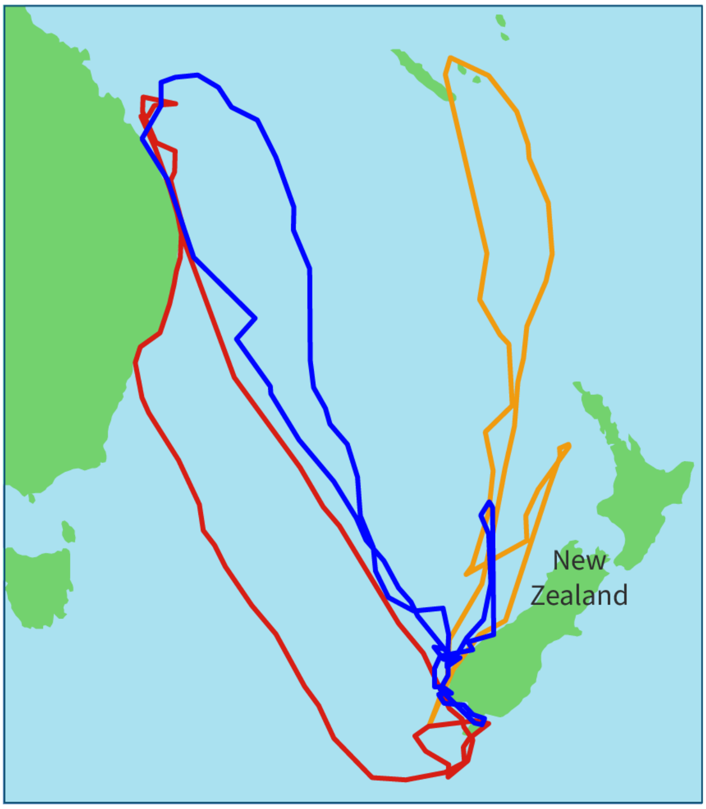

Figure 3. Migratory patterns of great white sharks.

More information for figure 3

The image is a map illustrating the migratory patterns of great white sharks. The map shows the ocean surrounding New Zealand, which is highlighted in green. Various colored lines represent different shark migration routes.

1. A red line indicates a route starting from the east coast of Australia, moving southward, bending towards New Zealand, and making a loop around its southern coastline.
2. A blue line starts near the same east coast of Australia, also proceeding southward but slightly offshore compared to the red route, looping around a similar region near New Zealand, and then heading back towards its place of origin.
3. An orange line originates further north, traveling southeast, skipping any adjacent land masses, and heading for the northern waters around New Zealand, making a circling movement near the northeastern tip before either looping back or diverging slightly.

The background is a pale blue color to represent the ocean water, and 'New Zealand' is labeled on the map to provide geographic context. Lines indicate tracking paths of the sharks' movement patterns over time.

[Generated by AI]

International Mindedness

Climate change is having a significant impact on the migration patterns of many animals. As ocean temperatures rise and currents change, the distribution and abundance of prey species, as well as the timing of their

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seasonal availability, can be altered. This, in turn, affects the migration patterns of the predators that rely on these prey species for survival.

Changes in the patterns of predators can have cascading effects on the entire ecosystem because of the impact on predator—prey interactions, nutrient cycling and ecosystem productivity.

Adaptations for swimming in marine mammals

Mammals are a diverse group of endothermic animals that breathe air through lungs, give birth to live young, produce milk to feed their young and have hair or fur at some point in their life. Today, mammals are found on every continent and in virtually every habitat, from deserts and grasslands to forests and oceans.

Mammals are believed to have evolved from a group of terrestrial reptiles around 200–225 million years ago. Around 50–60 million years ago, a group of land mammals returned to spend all or most of their life in or near the water, evolving adaptations that allow them to survive in marine environments (see subtopic B4.1 (/study/app/bio/sid-422-cid-755105/book/big-picture-id-43536/)). But what are some of these adaptations? And how are they advantageous for an aquatic habitat?

Marine mammals, such as whales, dolphins, seals, sea lions and manatees, have evolved a range of adaptations for swimming in their aquatic environments. These adaptations include:

- Streamlined bodies that minimise drag, allowing for efficient movement through the water. Marine mammals also often have a thick layer of blubber under their skin, which helps to smooth out their body shape, reducing drag as they move through the water. This layer of fat also serves to insulate the marine mammals from cold water environments and provide some buoyancy.
- Adaptations of forelimbs to form flippers that are positioned on the sides of their bodies which are usually long and narrow, and can be used for steering, to generate lift and contribute to a streamlined shape.
- Adaptation of the tail to form a fat and wide fluke. Flukes can be used for steering and propulsion in the water by moving up and down in a sweeping motion, as opposed to the tails of fish, which move from side to side.
- Changes of the airways to allow periodic breathing between dives. Whales and dolphins have a specialised nostril called a blowhole on the top of their heads which allows them to breathe without stopping or lifting their head out of the water. The blow hole is covered by a muscular flap which, when contracted, opens the blow hole to allow air to enter and leave the lungs, and, when relaxed, covers and seals the blow hole to prevent the entry of water. Blowholes are also used for communications between dolphins and whales — producing the clicks and whistles that allows them to convey information.

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- Marine mammals have higher concentrations of the protein myoglobin in their muscle tissues. Myoglobin has a high affinity for oxygen, allowing marine mammals to store more oxygen and dive for extended periods of time.
- Many marine mammals have larger lungs relative to their body size and more capillaries surrounding their alveoli, allowing them to take in more oxygen with each breath.
- Many marine mammals have higher volumes of blood relative to their body size, allowing them to carry more oxygen. They also have a higher concentration of red blood cells in their blood, and higher concentrations of haemoglobin in their red blood cells, allowing their bodies to contain and transport more oxygen than non-marine mammals. See section B3.1.11—13 (/study/app/bio/sid-422-cid-755105/book/transport-of-oxygen-hl-id-44441/) for more information on haemoglobin.
- The large size of many marine mammals minimises their surface area-to-volume ratio which reduces heat loss in cooler ocean waters. This adaptation helps them to maintain their body temperature and conserve energy.

Try the research activity below to learn more about adaptations for swimming in marine mammals.

Activity

- **IB learner profile attribute:** Inquirer
- **Approaches to learning:** Research skills — Using search engines and libraries effectively
- **Time required to complete activity:** 20 minutes
- **Activity type:** Group activity

In groups of three or four students, each person should choose a marine mammal to research. You should aim to find out, within 10 minutes:

- Adaptations for movement: does it have a streamlined body shape, flippers of fins for propulsion, or other features that allow it to swim efficiently?
- Habitat and location: where does the marine mammal live? Does it inhabit coastal waters, open ocean, or both? Is it found in specific regions of the world's oceans?
- Reasons why your marine mammal locomotes and whether it migrates: does it migrate to find food, mate, or give birth? How far does it typically travel during its migration?

Once the 10 minutes is up, share your findings with your group. As a group, discuss the similarities and differences among the marine mammals in terms of their movement adaptations, habitat and locomotion strategies.

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At the end of the discussion, each person should share two interesting facts that they have learned from their own or another student's research.

5 section questions

B3. Form and function: Organisms / B3.3 Muscle and motility (HL)

Summary and key terms (HL)

Section Student... (0/0) Feedback Print (/study/app/bio/sid-422-cid-755105/book/summary-and-key-terms-hl-id-44819/print/) Assign

Higher level (HL)

- Movement is a change in position or location of an organism or body part relative to its surroundings. All organisms, whether motile or sessile, exhibit movement.
- Sarcomeres are the contractile units of skeletal muscles, and they are made of repeating arrangements of the contractile proteins, actin and myosin. During muscle contraction, actin filaments slide over the myosin filament, shortening the sarcomere.
- Sarcomeres also contain an elastic protein called titin, which prevents overstretching of a sarcomere, and acts to return a sarcomere to its original length following muscle contraction.
- Antagonistic muscles are pairs of muscle groups that work in opposing action. The biceps and triceps are an example of an antagonistic pair that work around the elbow joint to allow flexion and extension of the elbow. The internal and external intercostal muscles are antagonistic muscle pairs that work to move the ribs to facilitate breathing.
- There are two types of skeletons, exoskeletons and endoskeletons. Skeletons act as anchoring points for muscles and they work as levers to allow movement.
- Synovial joints are the joints between two or more articulating bones. They contain synovial fluid inside a fluid capsule and typically allow a wide range of motion. The hip joint is an example of a synovial joint.
- The range of motion in a joint refers to the type and amount of movement that is possible at that joint. The amount of movement is also referred to as a joint angle, and can be measured manually using a goniometer, or digitally using computer analysis.
- Locomotion is the ability of an organism to move its whole body from one place to another. Locomotion is necessary for foraging, escaping danger, finding a mate and migration.
- Marine mammals evolved on land and then returned to the oceans around 50—60 million years ago. Adaptations of marine mammals to their aquatic environment include a streamlined shape, adaptation of the forelimbs into flippers, and then tail into a fluke, and specialised airways.

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Key terms

Review these key terms. Do you know them all? Fill in as many gaps as you can using the terms in this list.

1. Muscles are specialised tissues in the body that ______ and relax to produce movement. Skeletal muscle cells are organised into muscle fibres, which contain repeating units called ______, which are made of actin and myosin. For muscle contraction to occur, actin filaments slide over myosin filaments, ______ the sarcomere. Sarcomeres also contain an elastic protein called ______, which prevents overstretching of the sarcomere and returns the sarcomere to its original length after muscle contraction.
2. ______ muscles, such as the external and internal intercostal muscles, work in pairs to produce movement in opposite directions. When one of the muscles in the pair contracts, the other relaxes and vice versa.
3. ______ act as anchorage points for muscles and as levers to produce movement. ______ occur where two or more bones meet. ______ joints contain synovial fluid contained within a joint capsid and typically allow a wider range of movement than more static joints.
4. Motile organisms are able to locomote, whereas ______ organisms are fixed in one place. There are many reasons why locomotion is necessary, including ______, escaping danger, finding a mate and migration.
5. Adaptations of marine mammals to spend all or most of their lives in the ______ include a streamlined shape, adaptation of forelimbs into flippers and the tail into a ______, and specialised airways.

contract | sessile | Antagonistic | sarcomeres | Synovial | titin | fluke | ocean | foraging | Joints | Bones | shortening

Check

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Interactive 1. Muscle and Motility.

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B3. Form and function: Organisms / B3.3 Muscle and motility (HL)

Checklist (HL)

Section Student... (0/0) Feedback Print (/study/app/bio/sid-422-cid-755105/book/checklist-hl-id-44820/print/) Assign

Higher level (HL)

What you should know

After studying this subtopic you should be able to:

- Recognise the concept of movement in different species.
- Outline the structure of a sarcomere.
- Explain how a sarcomere contracts.
- Outline the role of titin and antagonistic muscles in muscle relaxation.
- Describe the structure and function of motor units in skeletal muscles.
- Outline the role of the skeleton as anchorage for muscles and as levers.
- Explain the role of the different components of a joint.
- Compare the range of motion of a joint.
- Explain the antagonistic action of the internal and external intercostal muscles.
- Give examples of reasons for locomotion.
- Describe adaptations for swimming in marine mammals.

B3. Form and function: Organisms / B3.3 Muscle and motility (HL)

Investigation (HL)

Section Student... (0/0) Feedback Print (/study/app/bio/sid-422-cid-755105/book/investigation-hl-id-44821/print/) Assign

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Higher level (HL)

- **IB learner profile attribute:** Thinkers

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- **Approaches to learning:** Thinking skills
    - Applying key ideas and facts in new contexts
    - Engaging with, and designing linking questions
- **Time required to complete activity:** 30 minutes
- **Activity type:** Individual/pair activity

Your task

The term 'joint angle' refers to the angle that is formed between a bone and a joint. It is used as a measurement of the amount of movement that is possible at a joint. Joint angles are typically measured in degrees, with zero being the anatomical or neutral position of the bones forming the joint. When a bone moves away from this position, the joint angle increases. Joint angles can be measured manually using a goniometer or digitally using computer analysis, or from images using a protractor.

In this investigation, you may work as an individual or in a pair to partially design and carry out an investigation on joint angles. You are provided with 24 measurements and 6 images showing the maximum range of motion of hip flexion for six different groups of individuals:

- Five 15-year-old females
- Five 15-year-old males
- Five 30-year-old females
- Five 30-year-old males
- Five 50-year-old females
- Five 50-year-old males

The data is for the maximum range of motion (ROM) of hip flexion. In each group, you have been provided with 4 measurements, as shown in **Table 1**.

Table 1. Data for 30 individuals.

Individual	Biological sex	Age	ROM (°)
1	Female	15	136
2	Female	15	136
3	Female	15	135
4	Female	15	134
5	Female	15	____

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Individual	Biological sex	Age	ROM (°)
6	Female	30	135
7	Female	30	134
8	Female	30	133
9	Female	30	134
10	Female	30	____
11	Female	50	130
12	Female	50	132
13	Female	50	132
14	Female	50	130
15	Female	50	____
16	Male	15	137
17	Male	15	134
18	Male	15	136
19	Male	15	133
20	Male	15	____
21	Male	30	131
22	Male	30	129
23	Male	30	130
24	Male	30	131
25	Male	30	____
26	Male	50	127
27	Male	50	126
28	Male	50	128
29	Male	50	128
30	Male	50	____

Complete your data sets by measuring the flexion of the hip as shown in **Figure 1,** using the images for individuals 5, 10, 15, 20, 25 and 30, provided in the download below.

[Joint angle images (https://d3vrb2m3yrmyfi.cloudfront.net/media/edusys_2/content_uploads/Biology B3.3.13 Joint angle images.77f68e7bbd894c31af3d.pdf)]

The dependent variable (the thing you measure) will be the joint angle of the hip and you will measure this using a protractor, measuring from the joint axis, an imaginary line that runs through the centre of a joint. Line your protractor up with the joint axis and measure the largest angle created by movement of a bone in a particular direction.

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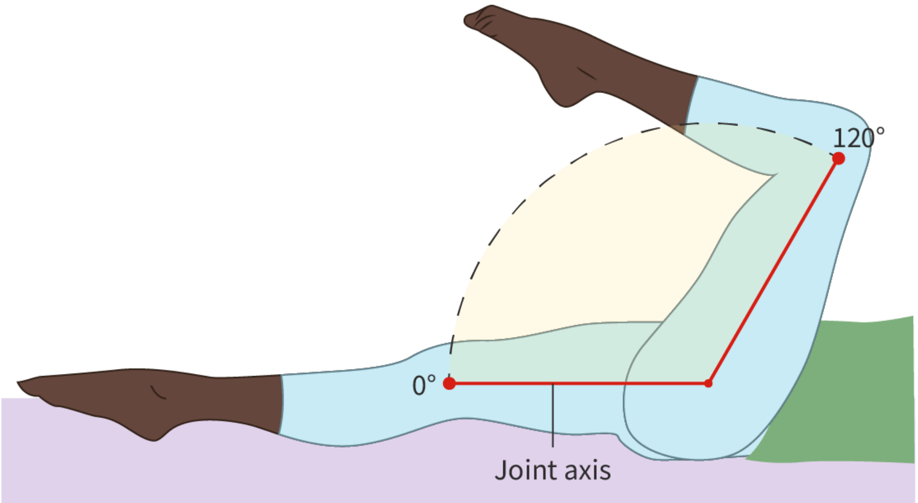

Figure 1. Measure from the joint axis to the largest angle of movement.

You might choose to investigate the relationship between ROM of flexion of the hip with age, or with biological sex.

Consider your control variables. As you are only provided with a limited number of images and only the age and biological sex of the individuals, you might want to consider what control variable you would implement if you had a larger participant base and more information about the individuals. This might include, for example, the average weekly duration, intensity and type of activity that participants do, and the extent to which participants have warmed up prior to the investigation.

Once you have specified your independent and dependent variables, construct a research question. You may also want to mention any pertinent control variables.

Is there a relationship between joint angle of the hip flexion and age, in males aged 15-30- and 50-years.

Construct a data table and collect your results.

Practical skills

Tool 1: Experimental techniques — Measuring variables

A reminder of key terms

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- The **independent variable** is the thing that you manipulate in an investigation to determine its effect on the dependent variable.
- The **dependent variable** is the thing that you measure or observe.
- **Control variables** are the things you keep the same to ensure that the effect on the dependent variable is solely due to the independent variable.

B3. Form and function: Organisms / B3.3 Muscle and motility (HL)

Reflection (HL)

Section Student... (0/0) Feedback Print (/study/app/bio/sid-422-cid-755105/book/reflection-id-46878/print/) Assign

Teacher instructions

The goal of this section is to encourage students to reflect on their learning and conceptual understanding of the subject at the end of this subtopic. It asks them to go back to the guiding questions posed at the start of the subtopic and assess how confident they now are in answering them. What have they learned, and what outstanding questions do they have? Are they able to see the bigger picture and the connections between the different topics?

Students can submit their reflections to you by clicking on 'Submit'. You will then see their answers in the 'Insights' part of the Kognity platform.

Higher level (HL)

Reflection

Now that you've completed this subtopic, let's come back to the guiding question introduced in The big picture (/study/app/bio/sid-422-cid-755105/book/big-picture-hl-id-43535/).

- How do muscles contract and cause movement?
- What are the benefits to animals of having muscle tissue?

With these questions in mind, take a moment to reflect on your learning so far and type your reflections into the space provided.

You can use the following questions to guide you:

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- What main points have you learned from this subtopic?
- Is anything unclear? What questions do you still have?
- How confident do you feel in answering the guiding questions?
- What connections do you see between this subtopic and other parts of the course?

Once you submit your response, you won't be able to edit it.

0/2000

Submit

Rate subtopic B3.3 Muscle and motility (HL)

Help us improve the content and user experience.

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