PERFORMANCE TRAINING ACADEMY

# Anatomy & Physiology

Full content for both the
Level 2 Certificate in Fitness Instructing &
Level 3 Certificate in Personal Training

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**Contents**

# Chapter Two: Anatomy and Physiology

**Introduction**

This chapter is to be broken down into many sub-chapters, giving you a great reference point for your study as well as when needed once you are actively working as a Fitness Professional.

It is of upmost importance that you continue to recap and learn further about the bio-mechanics and workings of the human body. A great fitness professional won't just know how to programme for an individual, but will know how to help improve weaknesses and imbalances within the body, knowledge of Anatomy and Physiology is key to be able to do this.

## The Musculoskeletal System

**Unit Objectives**

Our first objective is to understand the biomechanics of the human body. We can do this by learning about the skeletal system, and then how the muscles are layered upon the skeleton.

By the end of this unit we want you to have a good subject knowledge of the following:

- The main bones of the skeleton
- Joint types and joint actions
- How exercise can create a strong and healthy skeletal system
- The main muscles of the body
- Muscle contractions and fibre types

We will start by going through the skeletal system before bringing the muscles into the equation. This will allow you to build up your knowledge of bones and terminology before recapping them again by layering the muscles across specific joints.

# The Skeletal System

In this section, we will look at the structure and function of bones and joints in the skeleton, as well as how shape and structure (ie, form) relates to how this part of the body works (ie, function).

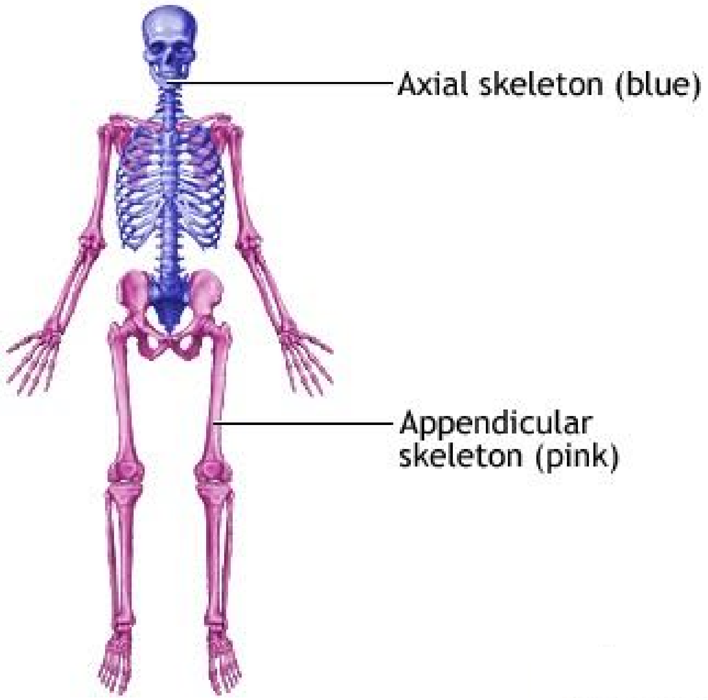
The aim of this section is to understand how the skeletal framework is constructed and how the joints allow specific ranges of movement.

By the end of this section, the learner should be able to:

- describe the basic function of the skeleton
- identify the structures of the axial skeleton
- identify the structures of the appendicular skeleton
- explain the classification of bones
- explain the structure of a long bone
- explain the stages of bone growth
- describe posture, in terms of: curves of the spine, neutral spine alignment, potential ranges of motion of the spine and postural deviations
- describe the classifications of joints
- describe the structure of synovial joints describe the types of synovial joint, their range of motion and injury risk
- describe joint movement potential and joint actions
- identify the anatomical axis and planes with regard to joint actions and exercise.

The framework of the human body is constructed of bones, joints and cartilage and is called the skeletal system. Without this framework, we would be unable to perform movements such as walking, squatting or any type of exercise.

The human body is made up of 206 bones, this section will focus on only about 30 of these, which are the major bones associated with the spine and the upper and lower limbs. The skeleton is divided into two parts:




1. axial skeleton - the skull, ribs, sternum and spine (blue area in left-hand image)

2. appendicular skeleton - upper and lower limbs, plus the bones forming the 'girdles' (pink area in the right-hand image), which connect the limbs to the axial skeleton. These girdles are the pelvic (hip) girdle and the pectoral (shoulder) girdle.

## Skeleton functions

The skeleton has five main functions.

1. **Movement** - the skeleton provides a series of independently movable long bones that act as levers. Muscles attach via tendons to these bones and when they contract, they pull on the bones/ levers, causing movement.

2. **Storage** - bones serve as storage areas for mineral salts, such as calcium and magnesium phosphate, both of which are essential for bone growth and health. Bone owes its hardness (ie, compression strength) to these mineral deposits. A deficiency in these minerals can contribute to the bones becoming weaker and brittle (a condition known as osteoporosis).

3. **Protection** - the skeleton protects the delicate internal structures and vital organs. For example, the skull protects the brain, the ribcage protects the heart and lungs, the vertebral column protects the spinal cord that runs down the middle of it and the pelvis protects the abdominal and reproductive organs.

4. **Shape/structure** - the skeleton gives the body its characteristic shape and provides a framework for attachment of muscles to the body. There are three main body types, or somatotypes, each with its own characteristics. They include:

- ectomorph - typically tall and thin, with narrow shoulders, hips and chest
- endomorph - rounded appearance, with wide hips and narrow shoulders
- mesomorph - muscular physique, with wide shoulders and narrow hips.

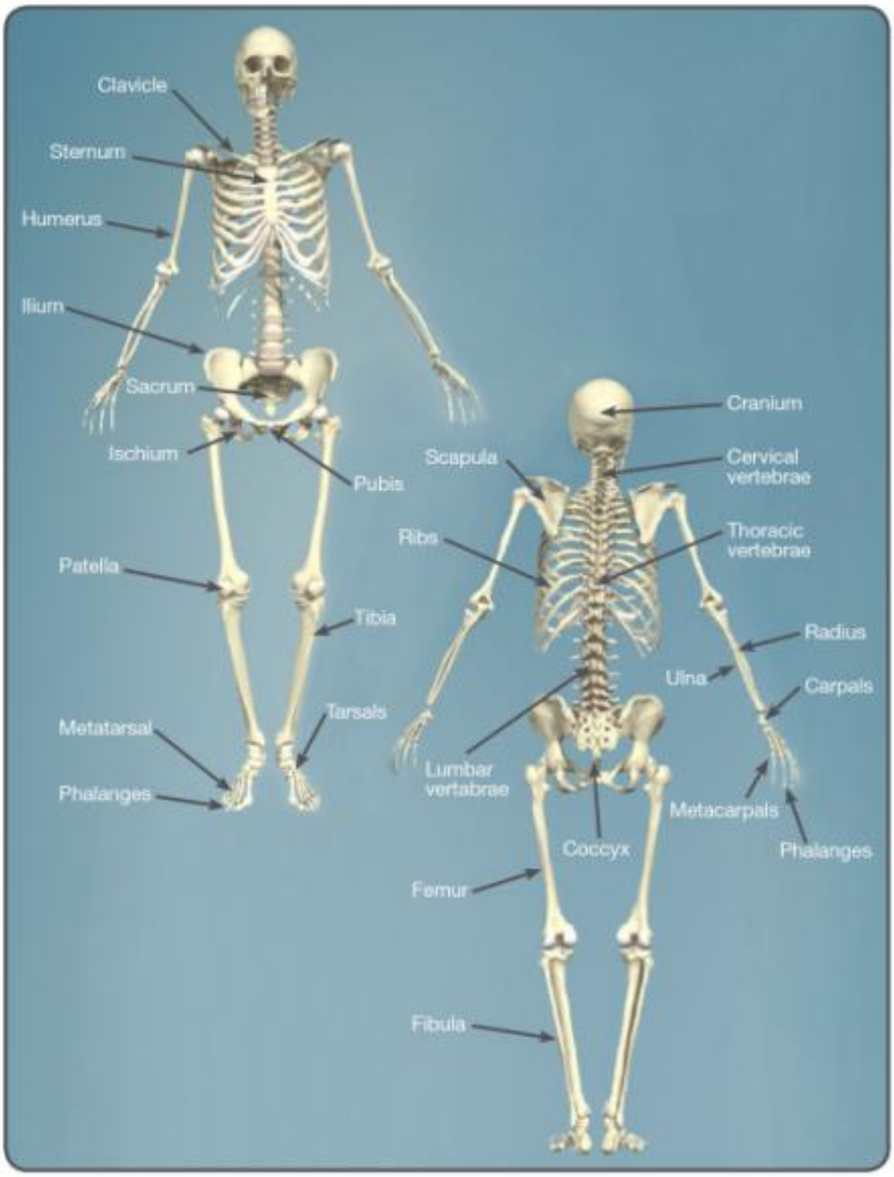
5. **Production** - the bone marrow that is contained within certain bones constantly produces red and white blood cells.
Red blood cells contain haemoglobin, which facilitates gaseous exchange, the exchange of oxygen and carbon dioxide.
White blood cells are dedicated to defending the body against infection, disease and foreign materials.

**Gender differences of the skeleton**

There are only minor differences between the male and female skeleton. Generally, male bones tend to be heavier than the corresponding bones of females. Commonly, females have a greater carrying angle at the elbow joint, a smaller femoral head at the hip joint and a wider pelvis to accommodate childbirth. While the alignment of the female pelvis is necessary for childbirth, it is not the best alignment for performing exercises involving the legs. This is because a wide pelvis makes the position of the hip joints wide, which makes the femurs slope inwards to compensate. This wider pelvis and alignment of the knees may cause the knees to roll inwards during some exercises. This angle between the hip joints and the knees is often referred to as the 'Q angle'. In contrast, the narrower male pelvis allows more vertical femurs - an alignment that is much more efficient for leg exercises.

**The major bones**

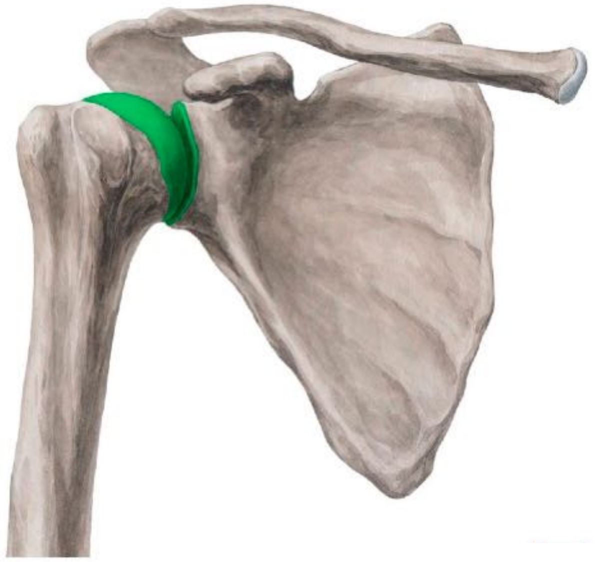
The images on this page illustrate the major bones in the skeleton.




The main structures of the skeleton are:

- pectoral, or shoulder, girdle
- upper limbs
- pelvic, or hip, girdle
- lower limbs  vertebral column, or spine.

**The pectoral, or shoulder, girdle**



The pectoral, or shoulder, girdle is composed of a double set of two bones on the right and left sides of the body. The clavicles are slender, doubly curved long bones that run horizontally across the upper chest and can be felt just below the neck.

Try this - run your fingers along the base of your neck. There you can feel the clavicles running horizontally.

Each clavicle articulates at the top of the shoulder with the acromion process of the scapula (acromio-clavicular joint or AC joint) in a gliding synovial joint and with the top end of the sternum (the sterno-clavicular joint) at the shoulder's front. The sterno-clavicular joint is a synovial saddle joint, but it also has a cartilaginous disc that absorbs considerable stress (eg, when falling on the shoulder). In fact, this joint is so strong that the clavicle itself is much more likely to break with the jarring that occurs.

The clavicle gets its name from the Latin word clavicula (meaning 'little key') because the bone rotates along its axis like a key when the shoulder is abducted (arm lifted out to the side). This is the most commonly broken bone in the body.

The scapulae are roughly triangular-shaped, thin flat bones that partially cover the back of ribs 27. The posterior surface of each scapula has a raised ridge along its length that ends in a large bony process called the acromion process. This articulates with the clavicle and is called the acromio-clavicular joint (AC joint). It can be felt at the top of the shoulder and is the point of contact of each scapula with the rest of the central skeleton. Each scapula is anchored in place by the many muscles of the back and shoulder joint, giving incredible mobility to the whole shoulder girdle and the associated upper limbs.

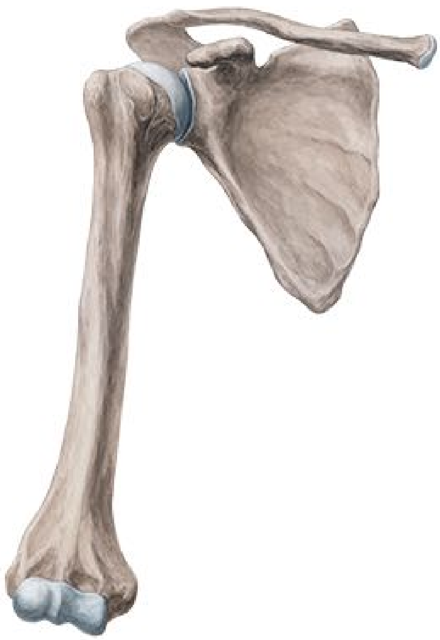
The scapula is often referred to as the shoulder blade and has two unique motions - first, it moves sideways around the ribs in the protraction and retraction movements, and second it rotates in the abduction and adduction movements.

There is a depression - the glenoid cavity - laterally at the top of the scapula (directly below the AC joint). This forms the socket that the head of the upper arm bone (the humerus) fits into, forming a synovial ball and socket joint.

Movements that can occur at the shoulder girdle are:

- Protraction and retraction
- Elevation and depression

**The upper arm and shoulder joint  (The glenohumeral joint)**



The only bone in the upper arm is the humerus. It typifies a long bone with its lengthy diaphysis and two very prominent epiphyses. The proximal epiphysis is smooth and rounded. It fits into the glenoid cavity of the shoulder girdle.

This upper arm bone is pronounced in the same way as the word 'humorous' (as in 'funny') - and it is the ulna nerve running down to the elbow that can be knocked and is described as hitting the 'funny bone'.

The shoulder joint is quite shallow, giving a large range of movement. There are ligaments that attach bone to bone, and these work with the fibrous joint capsule to aid stability. However, the majority of shoulder stability comes from the muscles surrounding the joint. As such, the shoulder joint provides a large range of movement, but can be prone to injury.

The stability of the shoulder joint comes primarily from a small group of muscles called the rotator cuff. These muscles originate on the scapula and attach at four different points on the head of the humerus to pull it into the glenoid cavity. These muscles are often weak due to overworking of the larger, more dominant muscles of the shoulder such as pectoralis major, the latissimus dorsi and deltoids. This can compromise the efficiency of movement in the shoulder joint and increase the risk of injury.

Movements that can occur at the shoulder (glenohumeral) joint are:

- Flexion - Extension (including hyperextension)
- Horizontal flexion (horizontal adduction)  - Horizontal extension (horizontal abduction)
- Abduction - Adduction
- Rotation
- Circumduction

The shoulder joint is susceptible to damage both from repetitive strain and from uncontrolled acute movements beyond the normal range. Dislocation (disengagement of the humeral head) is common and in the long-term damage to the joint tissues, the bone and the surrounding musculature is prevalent.

**The lower arm, elbow and wrist joints**

There are two long bones in the lower arm - the radius and the ulna. The ulna is slightly longer than the radius and has a much more prominent proximal head called the olecranon process that can be felt at the elbow joint. It is the deep trochlear notch on this process that forms the hinge joint with the distal head of the humerus, although the head of the radius is partially involved too.

The radius is named after the round, disc-like head that connects it to the humerus. This round head of the radius rotates (or pivots) at the elbow to enable the body to perform palm-up and palm-down motion without any movement at the elbow.

Try this - hold your arms out in front with your palms down, so that the ’ulna sits ’u’nderneath the palm radius. The radius rotates to turn the hand over. The ulna only flexes and extends, because it is a hinge joint.

Strong ligaments also hold the bones in place and help to limit movement around a single axis and in one plane (sagittal). This is a true hinge joint with only flexion and extension movements possible. In full extension, the head of the humerus hits the trochlear notch preventing hyperextension. This locking out, however, can cause the articulating surfaces to rub together, causing damage to the cartilage, the joint capsule and the surrounding ligaments.

The radius and the ulna are connected to each other by a synovial pivot joint, both at their proximal and distal ends, called the radioulnar joints. They are also connected down their whole length by a fibrous, slightly movable membrane. It is the radioulnar joint (pivot joint) at the proximal end (nearest the elbow), and the interosseous fibrous membrane which enable pronation and supination of the hand.

This movement is really the radius rotating over the ulna so that the two bones cross. In contrast, it is the radius that is far more prominent at the wrist. Here it articulates with two of the carpal bones to form a condyloid synovial joint that allows flexion, extension, abduction and adduction. The ulna has a very small connection here via a small cartilaginous disc; it is not, therefore, involved in movement.

**The wrist and hand**

The hand is composed of 27 small bones. The true wrist is composed of eight cuboid bones, the carpals, which form gliding synovial joints, giving a large degree of flexibility to the whole hand. The carpals are roughly arranged in two rows and the two biggest bones of the first row form the synovial joint with the radius.

Try remembering these as the little 'c’luster of 'c'arpal bones lying between the wrist and fingers. The number of bones and flexibility between these bones makes human hands very flexible.

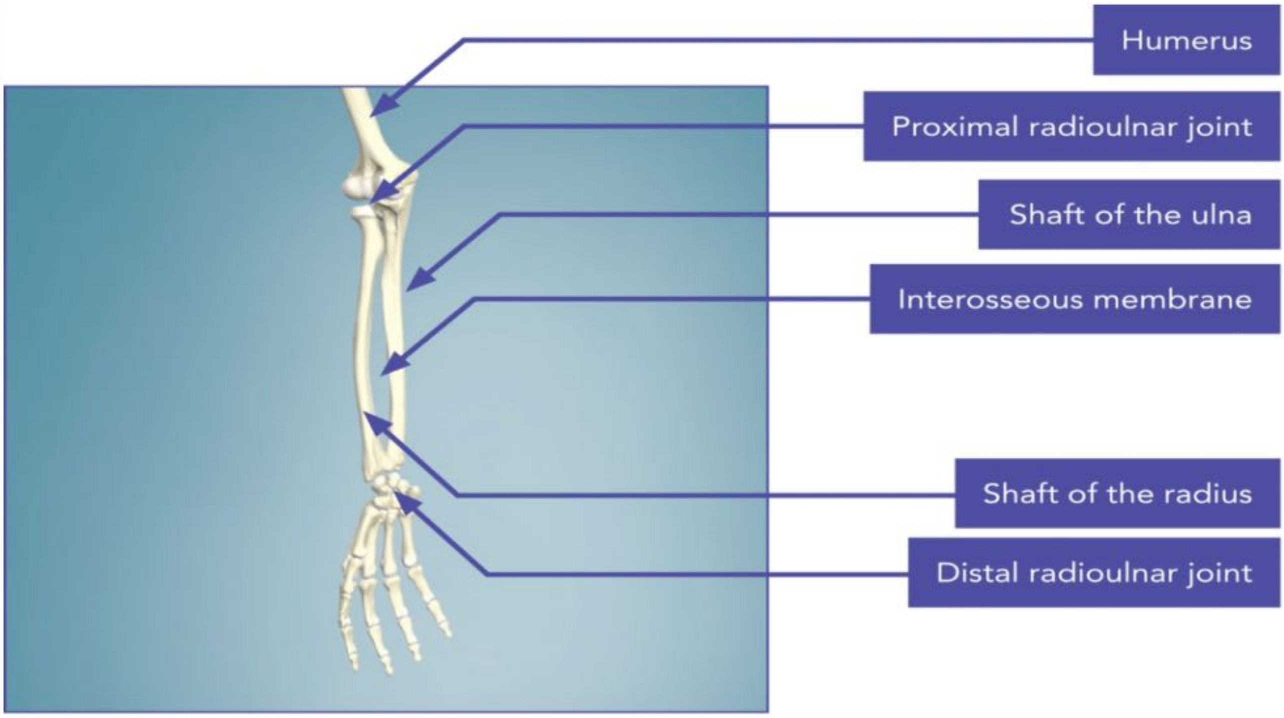
The second row articulates with the five metacarpals that radiate out to form the palm. These biaxial joints enable both flexion and extension of the fingers, but also abduction and adduction of each of the fingers.

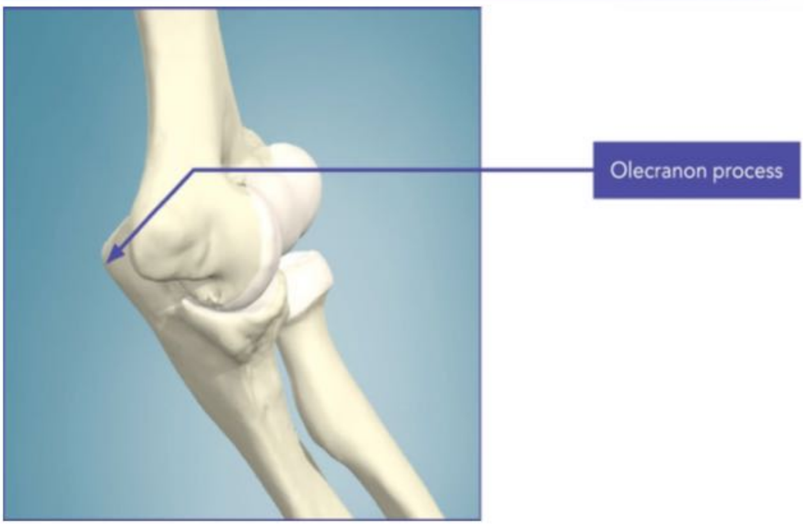
The four fingers (or phalanges) are composed of three bony segments, articulating with each other via synovial hinge joints. The thumb, however, has only two segments. The articulation between the thumb and the first metacarpal is a synovial saddle joint. All movements apart from rotation are possible here. It is the movement at this joint which allows us to oppose our fingers and thumb to grip or to pick things up.

Meta is the Greek word for ’after’ or beyond - and the ‘meta’ carpals come ’after’ the carpals. It is easy to confuse carpals and metacarpals (in the hands) with tarsals and metatarsals (which are equivalent bones of the feet), just remember that ’t'oes go with ’t'arsals. The large number of bones and joints in the hands and feet means that these structures are extremely flexible and offer great dexterity.

The large degree of hand movement allows for an equally large range of functional actions (including non-verbal communication). This means that there is equally great potential for damage to the array of muscles, tendons, ligaments, joint capsules and nerves in this area.

Many tendons, nerves and blood vessels are channelled through an anterior groove in the wrist and palm known as the carpal tunnel. This is a common area of injury known as carpal tunnel syndrome. One of the nerves passing through the carpal tunnel becomes compressed causing pain and numbness in the thumb, index and middle fingers and half of the ring finger. Repetitive flexion and extension of the wrist is a common cause.

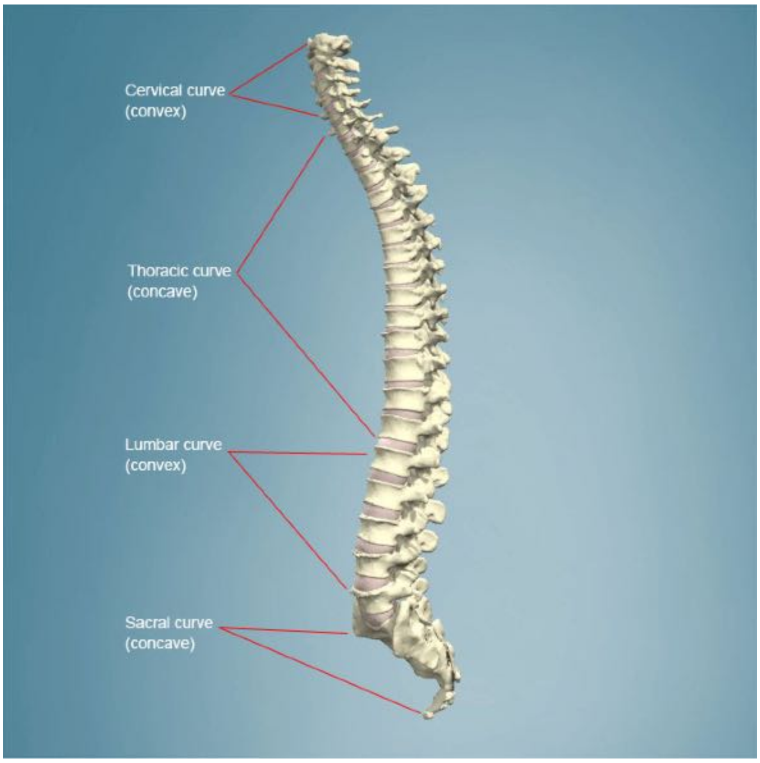


**The vertebral column, or spine**

The spine is the main foundation or starting point in the framework of the body. The head sits on top of this column and the ribs surround it, protecting the organs inside.

The shoulder girdles are suspended from this framework and lead into the arms. At the bottom of the spine is the pelvis, which leads down to the lower limbs. The vertebral column is made up of individual bones called vertebrae. The names of the vertebrae indicate their location along the length of the vertebral column. There are 33 vertebrae in total.




**Cervical vertebrae (7 bones)**
Situated in the neck, the first vertebra is called the atlas bone. The atlas bone supports the skull and forms a pivot joint with the second vertebrae, which is called the axis. This pivot joint allows us to turn our heads from side to side.

**Thoracic vertebrae (12 bones)**
The 12 thoracic vertebrae form joints with the ribs to produce the ribcage, which protects the heart and lungs, as well as the abdominal organs, from injury.  They are intermediate in size between those in the cervical and lumbar regions and they get larger as they progress down the spine.

**Lumbar vertebrae (5 bones)**
These vertebrae are largest of all. This area is most often the culprit in lower back pain, due to the amount of movement that takes place here.

**Sacral Vertebrae (5 bones)**
The sacral vertebrae are fused to form the sacrum, which joins together the two halves of the pelvis.

**Coccygeal (3-5 bones)**
The coccyx is represented by 3-5 vertebrae, which are themselves fused and attached to the bottom of the sacrum.

The curves of the vertebral column centre the skull over the rest of the body, enabling a person to walk more easily and maintain an upright posture. They also reduce the amount of impact through the skeleton by dispersing shock and protecting the brain from shock waves that occur from movement.
In the above picture the cervical and lumbar regions are shown as convex, whilst the thoracic and sacral regions are concave. This gives the spine its characteristic S-shaped curvature which acts like a spring and dramatically increases its capacity to absorb impact without damage.

In addition, the vertebrae are joined together by cartilaginous intervertebral discs, which give the spine elasticity and compressibility. The discs themselves cannot provide the support needed to keep the column erect. This is achieved by bands of ligaments stretching along the vertebral column both anteriorly and posteriorly. The anterior ligament is a broad band attached to the bones and the intervertebral discs. The posterior ligament, however, is narrow and relatively weak. As such, it can easily be damaged when bending forward with momentum. There are also many short ligaments that connect each vertebra to the one just above and below it. Again, these are relatively weak and may be damaged with excessive movement.

The extent of the spinal curve varies considerably between individuals, sometimes genetically, sometimes because of poor posture or muscle tone in the supporting muscles. Deviation of spinal curvature will be looked at in the next section 'Posture and core stability'.

The spine is a flexible structure that affords the following movements:

- flexion and extension
- rotation
- lateral flexion and lateral extension.

The various sections of the spine produces the following movements in varying degrees, as follows:

- cervical - the most mobile part of the spine
- thoracic - less mobile than the cervical
- lumbar - very limited range of movement
- sacral - no movement possible
- coccyx - no movement possible.

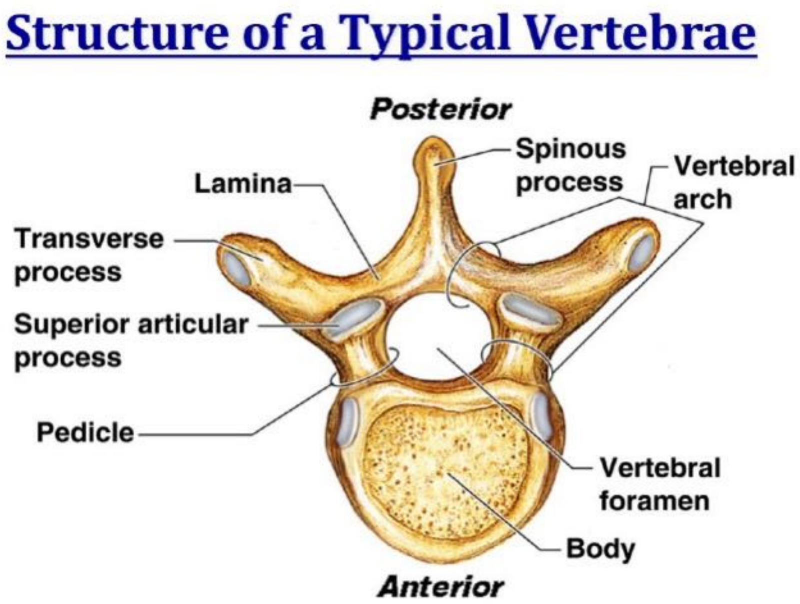
**Structure of the spine**

Each vertebra has a hole in the body of the bone to allow the spinal cord to pass through. One of the central roles of the bones of the vertebral column is to protect the spinal cord. In between each vertebral body lies an intervertebral disc. In the middle of each intervertebral disc is a soft, jelly-like nucleus. As well as preventing the vertebrae from rubbing against each other, this disc also acts as a shock-absorber against the impact of daily activities.

**Structure of a typical vertebra**

All vertebrae look roughly the same. They are irregular bones that have several spiny processes. Their most obvious feature is the large anterior bony body called the centrum that connects via the cartilaginous discs to the body of the adjoining vertebrae. Posteriorly, there is the vertebral arch composed of bony cylinders - the pedicles and lamina. The ends of these cylinders provide articulating surfaces called facets, covered with hyaline cartilage. These form gliding synovial joints with the facets of adjacent vertebrae and also provide attachment points for the back muscles. It is the orientation of these facet joints that largely determines the degree of movement in each section of the spine.

The body (centrum) and the vertebral arch surround an opening - the vertebral foramen. The foramens of all of the stacked vertebrae in the column provide a protective channel through which the spinal cord runs. Nerves exit the spinal cord through small gaps between the processes. In addition to their common features, the vertebrae in each of the regions have special characteristics that allow them to perform specialised functions and movements.




**Cervical vertebrae**
The first of the cervical vertebrae - the atlas - does not have a body. It is, essentially, a bony ring on which the skull sits and balances. The synovial joints between the atlas and the skull allow nodding and lateral flexion movements.
The second cervical vertebra is the axis, which carries a rounded projection called the odontoid process. This inserts into the ring of the atlas allowing rotation movements. The facet joints here are angled backwards slightly (coronal) and allow considerable movement in all planes.

**Thoracic vertebrae**
The thoracic vertebrae have heart-shaped bodies. Each of them has two facets on each side - one to articulate with each of the ribs and the other with its adjacent vertebrae. As the ribs are also attached to the sternum anteriorly, the whole of the thorax is enclosed by a protective cage housing the heart and the lungs. The facet joints here are more vertical and, individually, they have a very small range of movement. However, because the thorax has the largest number of vertebrae, it is the most movable area of the spine, allowing flexion, extension, lateral flexion and some degree of rotation.

**Lumbar vertebrae**
The lumbar vertebrae are the ones that have to cope with the most impact stress during jumping and running. Therefore, they have large sturdy bodies and thick intervertebral discs. The orientation of the facet joints means that the five vertebrae are more or less locked together, so that the minimum amount of rotation may occur. Any excessive movements that attempt to rotate the lumbar vertebrae may damage the facet joints dramatically, decreasing the stability of the whole column. The lumbar vertebrae can perform lateral flexion. Although flexion and extension is possible, care must be taken to perform these movements with control and within a range that

does not stretch the discs. The lordotic curve here also has a critical role to play in spinal stability and should be neither too flat nor too hollow. Many popular exercise formats, particularly Pilates, focus on encouraging what is termed the 'neutral spine' position. This is the position of the spine where all the curves are in their optimal position to absorb and transfer force or impact.

**Sacrum and coccyx**

The vertebrae of the sacrum are fused together to provide a solid base. The coccygeal vertebrae are also fused where they might once have formed a tail. As already mentioned, some people have more bones here than others. Particularly in those with five bones, some discomfort may be felt when sitting on a hard surface.

**Exaggerated curvatures of the spine**

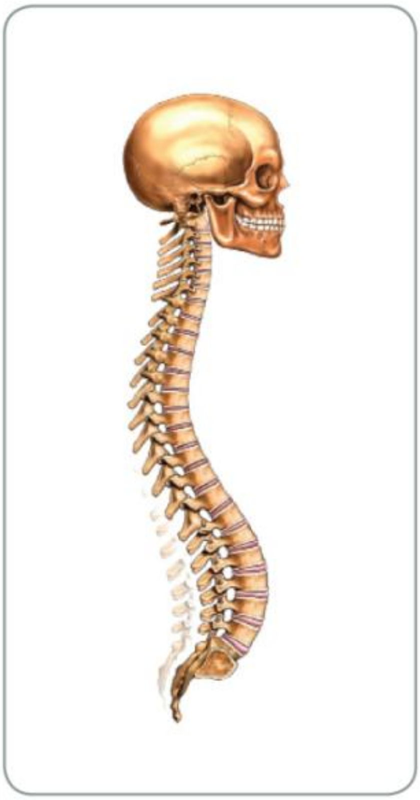
Genetics and lifestyle factors can cause curvature of the spine to become exaggerated or excessive, which gives a distorted appearance to an individual's posture. This, in turn, may lead to additional problems and symptoms in the form of stiffness, tenderness, back pain and a lack of mobility.

Factors relating to spine curvature include:

- Fashion (i.e.high heels): this can cause shortening of the calf muscles, hamstrings and increased curvature of the lower spine (lordosis)
- work/school (eg, poor positioning of work desk and chair, driving, or positioning while operating a checkout or computer, carrying heavy bags, etc.): these activites can stretch the upper back muscles and shorten the upper chest muscles, which leads to an increased 'hunch' or kyphosis
- emotional state: lack of confidence, stress, low self-esteem, etc. may affect the way an individual holds their posture
- sport: sports such as golf, tennis or rowing may lead to over development of certain muscle groups on one side of the body, thereby affecting posture
- hereditary conditions: conditions such as scoliosis may be inherited, as may other conditions that affect muscles (eg, muscular dystrophy) injuries: soft tissue strains and sprains may lead to changes in posture. The development of scar tissue may reduce flexibility of muscles and range of movement, leading to postural changes
- age: growth spurts, puberty, the menopause and osteoporosis can all affect connective tissue and bone structure, which may affect posture
- pregnancy: the weight of the baby, increasing body size and relaxing of spinal ligaments can lead to an exaggeration of spinal curvature during pregnancy
- disability: some factors of an individual's disability can lead to poor posture
- obesity: distribution of body fat on certain parts of the body and increasing body size can affect the shape of the spine.

Note: Any exaggerated curvatures of the spine are referred to as kyphosis, lordosis or scoliosis, depending on the direction of the curve. Each condition is characterised by a distinct spinal curvature.

**Lordosis**



This is an exaggerated inward curvature of the lumbar spine that gives the lower back a hollowed appearance and can sometimes make the buttocks appear more prominent.

Lordosis can be caused by poor posture, and can also be brought about by development problems during childhood or pregnancy.  A number of muscles are affected by lordosis.

These muscles include:

- erector spinae (shortened)
- gluteus maximus (lengthened)
- hamstrings (usually overactive to substitute for weaker gluteals)
- hip flexors (shortened)
- transverse abdominis (weakened)
- rectus abdominis (lengthened).

Lordosis is an excessive curvature of the lumbar spine (hyperextension), where the pelvis tilts forwards too much and the abdomen moves forwards relative to the plumb line, whilst the buttocks move backwards. The cause can be genetic, or it can be related to some sporting activities where lordotic posture is encouraged, or perhaps to the client carrying too much weight in the abdominal area because of pregnancy or obesity.

The excessive curve in the lumbar spine can place too much pressure on the intervertebral discs, compressing them in particular at their posterior edge. Also, the small, synovial facet joints between each of the vertebrae may become overloaded. Either way, lower back pain will result.

When correcting lordosis, positional awareness is usually focused on the tilt of the pelvis. Lordotic posture typically has too much pelvic forward tilt, which in turn causes the lumbar spine to curve too much. The client therefore needs to learn how to find a more neutral pelvis position.

Several muscles are involved in holding the pelvis in its neutral position, and they need to be balanced. In lordosis, when the pelvis is tilted forwards, a typical pattern of imbalance known as the ‘pelvic crossed syndrome’ is often present. The lumbar erector spinae and the hip flexor muscles (rectus femoris, tensor fascia latae, iliacus and psoas major) become shortened. The antagonistic muscles to these, the abdominal group and the gluteus maximus, are weakened and lengthened.

The external obliques have an important role in controlling forward pelvic tilt, so these would need particular attention to strengthen them. Also, the deep stabilisers (transverse abdominis and internal obliques) may also be weak and inactive.

A weak gluteus maximus means that the hamstrings have to work harder than usual to extend the hip when walking, running or climbing stairs. This can lead to hypertrophy and overuse of the hamstrings, although they may not necessarily be short.

Careful exercise selection is needed to target the gluteus maximus whilst minimising the involvement of the hamstrings. In this way, a careful programme of stretching and strengthening can, over time, help to re-establish correct pelvic tilt and eliminate lordotic posture.

**Kyphosis**

Kyphosis is where an individual has an exaggerated rounding or hump in the thoracic vertebrae, giving a slouched appearance, often with the head jutting forwards. This may result from a variety of causes, such as:

- genetics
- lifestyle factors that have led to bad posture (eg, sitting for long periods of time with bad posture in front of a computer)
- structural deformity of the spine that may occur at birth (a congenital defect) or as a result of degenerative disease, such as arthritis or prolapsed discs.

Whatever the cause of the kyphosis, the result is excessively shortened or lengthened muscles in the front and back of the upper body.

The main muscles affected include:

- pectorals (shortened)
- trapezius (lower and middle sections lengthened, upper section shortened)
- rhomboids (lengthened).

Kyphosis is an excessive curvature of the thoracic spine, where the head and shoulders move significantly towards the plumb line. It is often referred to as rounded shoulders. The cause can be genetic, or it can be related to the client's occupation, where they spend most of the day leaning forwards, peering at a computer screen. The cervical spine will often develop an excessive curve as well, in order to compensate, and to try and bring the head back towards the plumb line.

A kyphotic posture will have the effect of reducing the volume of the thoracic cavity, and making breathing less efficient. It affects the position of the scapulae and shoulder joint stability. Also, the resulting tension in the neck muscles is a common cause of headaches.

In terms of muscular balance, a kyphotic posture is characterised by tight muscles at the front of the torso and weakened muscles in the upper back. Stretching would therefore target muscles such as the pectoralis minor, the deep neck flexors, rectus abdominis (if the chest is depressed) and possibly levator scapulae or upper trapezius (if shoulder elevation is also present). A strengthening exercise would be appropriate for the middle and lower trapezius, and for the thoracic portion of the erector spinae. Rotator cuff muscles around the shoulder joint may also need to be assessed for correct functioning.

It is important that the strengthening exercises are performed whilst the client is holding the correct postural position and the muscles are at their optimum length. Lengthened muscles are inhibited by the nervous system and do not strengthen easily, and any strength gained would simply make them better at holding the wrong posture anyway.

**Scoliosis**

Scoliosis is a lateral, or sideways, curvature of the spine. It gives the appearance of an S-shape, rather than a straight line, when observed from the front or the back. Some of the bones in the spine may also rotate slightly, giving the appearance of unevenness in the waist or the shoulder.

Scoliosis is most commonly caused by a congenital defect (ie, something one is born with), but at times it can result from poor posture. This type of posture is not easy to correct and would require working with a specialist such as a physiotherapist rather than an exercise instructor.

Most people have a small degree of scoliosis because they have a dominant hand and leg that they use in everyday tasks, and therefore they are not perfectly symmetrical.

However, when the curvature becomes significant and easily noticeable, then health problems can result. The cause can be genetic - for example, one leg has grown longer than the other, which tilts the pelvis to one side. The spine then has to compensate by curving sideways in the opposite direction to maintain normal balance.

The cause can also be related to occupation, such as a postal worker who habitually carries a heavy bag on one shoulder. Or it could be related to a sport that uses one side of the body more than the other, such as tennis or javelin throwing. The underlying problem here is muscle imbalance.

Scoliosis is complicated, often related to structural defects, and is associated with a rotation of the spine as well. Any clients with a noticeable asymmetry of the spine should be referred to a medical specialist for a thorough examination before any corrective exercise is attempted.

Mild scoliosis due to muscle imbalance can often be improved by some very basic measures. For example, if the cause was carrying a heavy bag on one shoulder, then simply swapping shoulders regularly, or using a rucksack, would help alleviate the problem. Also, it is quite easy to stand in front of a mirror and obtain quick visual feedback of head and shoulder levels, so that correct positioning can be practiced regularly.

Muscle imbalance in scoliosis would exist between one side of the body and the other. To correct it, any training would therefore need to focus on isolateral exercises, where each side of the body works independently of the other so the stronger side cannot help the weaker side. For strengthening, this would include dumbbell exercises or resistance machines that are designed for isolateral work. For stretching, it would suggest comparing the range of movement of one half of the body with the other and stretching one limb at a time, so that imbalances can be reduced.

**The pelvic, or hip, girdle**

The pelvic girdle has the same function as the shoulder girdle. However, because the pelvis supports the weight-bearing lower limbs, this joint must provide greater stability. The trade-off for this stability is a reduced range of motion, particularly at the ball and socket hip joint, when compared with the ball and socket joint at the shoulder.

The pelvic girdle transmits the whole weight of the upper body down through the legs to the ground. It also plays a major role in ensuring the correct alignment of the spine (the neutral spine position). Unlike the pectoral girdle, it needs to be strong, stable and resistant to large ranges of movement. It is composed of two bones on each side. These bones are themselves made from three separate bones: the ilium, ischium and pubic bones, which fuse together indistinguishably, in adulthood.

The ilium has some similarities in shape to the scapula, as it is a broad, plate-like curved bone with a prominent outer rim, or iliac crest, which can be easily felt in most people and sometimes seen in thinner individuals. It is the posterior, medial edge of this plate that articulates with the fused sacral bones of the vertebral column in the load bearing sacroiliac (SI) joint. Although the lower section of this joint is a typical synovial joint, the articulating surfaces in the upper half are held very closely together by short strong ligaments, so there is no synovial cavity.

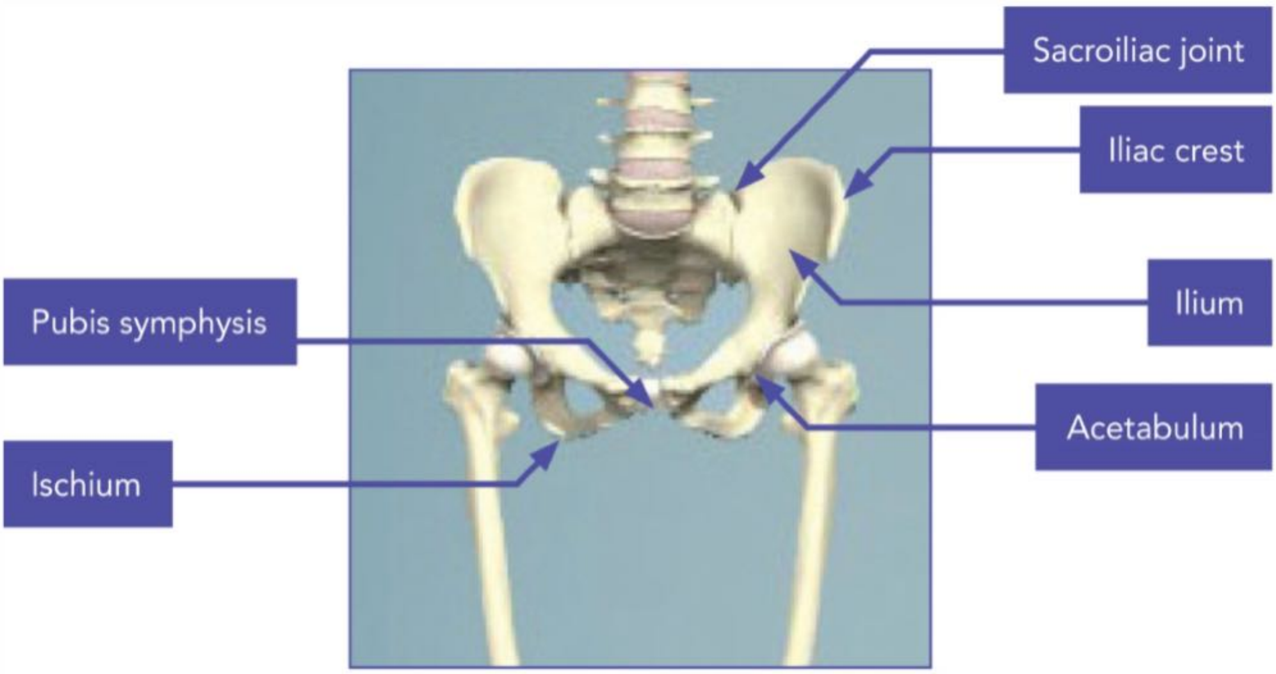
A tough fibrous joint capsule covers the whole joint. Consequently, joint movement here is severely limited and becomes more so in the elderly, when the synovial section of the joint can dry up and fuse. Some tilting movement, anteriorly and posteriorly only, is possible. During pregnancy however, the effects of the hormone relaxin can lead to excessive movement in this area resulting in pain on one or both sides of the joint.

There are a number of nerves that leave the spinal column at this point to supply the muscles of the hips and lower limbs, particularly the large sciatic nerve and the gluteal nerve. Poor posture, exaggerated pelvic tilt and any unwanted movement can place the SI joint and the attached lumbar vertebrae under severe stress. This can result in the compressing of nerves, over-stretching of ligaments, tearing of weak muscles, damage to the intervertebral discs and inflammation of the joint.

The bottom (inferior surface) of the ischium is especially thick and strong as it has to support the whole bodyweight while seated. The tiny bones of the coccyx can be prominent in some people. Consequently, some exercise positions can put pressure on both of these bones, causing pain to these individuals.

The pubic bones are joined together anteriorly by a cartilaginous disc, the pubis symphysis, which completes the pelvic bowl. This pad of cartilage between the two joint surfaces plays an important role in the stability of the pelvis. Stability is also dependent on ligaments, which are affected by the correct alignment of the SI joints. The pubis symphysis has a normal separation of 3-4mm, which can increase up to as much as 9mm in pregnancy due to the hormone relaxin. The effect of relaxin on the SI joints and pubis symphysis often leads them to become a source of discomfort. Any movement or pain is often diagnosed as pubis symphysis disorder (PSD). However, extreme separation is called diastasis symphysis pubis and needs to be specifically diagnosed by a medical practitioner. The general term given to pain in either area is pelvic girdle pain (PGP).

Where the ilium, ischium and pubic bones fuse laterally, they form a deep cup-shaped socket, the acetabulum into which the head of the thigh bone (the femur) fits. This socket is much deeper than its counterpart on the shoulder (pectoral) girdle into which the humerus fits, in keeping with the very different role of the pelvic girdle and lower limbs (support and stability) compared with the highly mobile shoulder girdle and arm.




The male and female pelvis is different in several ways. The differences are associated with childbirth in females. A wider pelvic bowl and anterior tilt is needed for the baby to pass smoothly through into the birth canal during childbirth.

**Male Pelvis**

- Narrow, shallow heart shaped pelvic bowl
- Pelvic angle is almost vertical
- The position of the acetabulum is almost vertical
- Small Q angle between hip and knee joints allowing more efficient transfer of force between the hip and knee joints

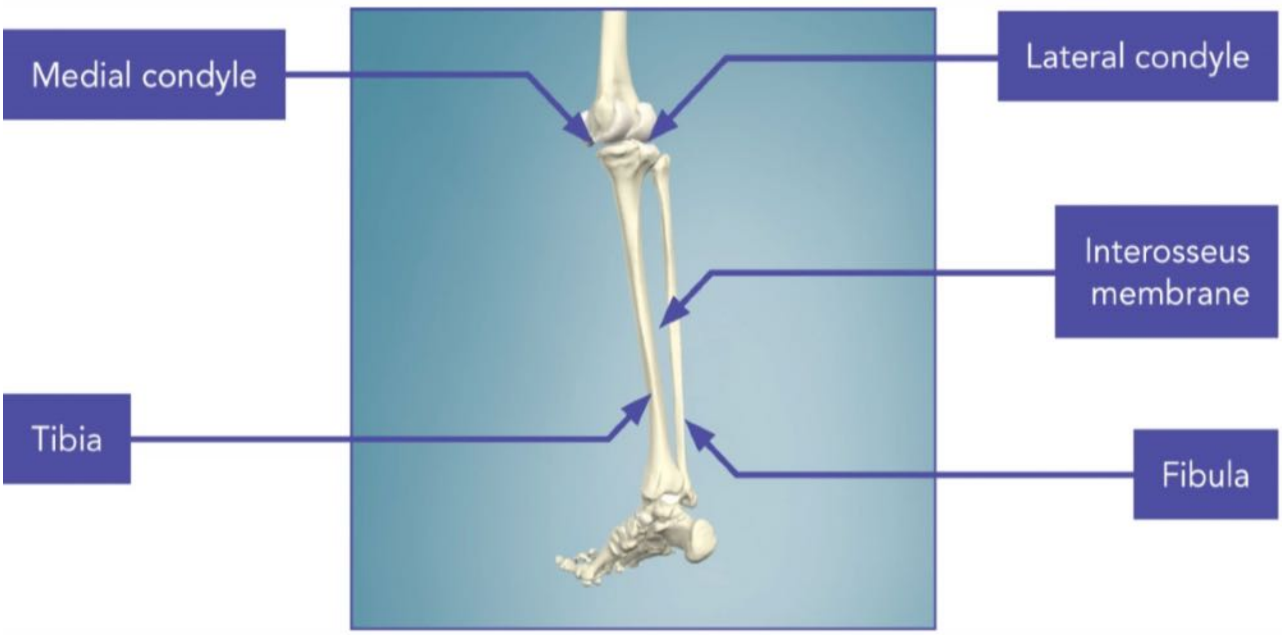
**Female Pelvis**

- Deeper, wider oval shaped pelvic bowl. Greater curvature in the sacrum
- Pelvic angle tilts anteriorly
- The position of the acetabulum has a slight posterior tilt
- Larger Q angle between hip and knee joints, causing less efficient transfer of force between hip and knee. This leads to a higher incidence of hip, knee and ankle injury in females engaging in impact activities such as running

The Q angle is the angle between vertical and an imaginary line running from the hip joint to the knee joint. The transfer of forces from the hip to the knee joint is more efficient the closer this line is to vertical. The femur is the longest, largest and strongest bone in the whole of the body. It has a pronounced ball-shaped head at its proximal end held by an equally obvious neck. At the base of the neck, the bone flares out laterally to form a collar that provides attachment sites for the muscles of the thigh and buttocks called the greater trochanter. On the medial side of the femur is the lesser trochanter. The ball fits snugly into the acetabulum of the pelvic girdle and is held in place by the labrum, a fibrocartilage lip.  It is held in place by both an internal ligament and strong external ligaments.
Flexion, extension, hyperextension, abduction, adduction, circumduction and medial and lateral rotation are all possible. Although this bone is strong, its weakest part is the neck area. This can be further weakened by osteoporosis in older females (and some males) and is vulnerable to fractures and breaks causing decreased mobility and pain. Hip replacement operations replace the bony neck and head of the femur with a metal prosthesis and have considerable success. Other interventions of a less radical nature are being developed and tested.

At the distal end, the femur widens again forming two rounded condyles (knuckle-like processes) that fit neatly into complementary condyles on the tibia (the lower leg) to form the knee joint.

**The knee joint and lower leg**




The arms and the legs are based on a similar plan. Consequently, the lower leg is composed of two long bones held together at their proximal end by a gliding synovial joint. This is held along the whole length of their diaphyses by an interosseous fibrous membrane, where the distal end forms a fibrous joint to ensure the lower leg is strong and stable (unlike the radius and ulna).

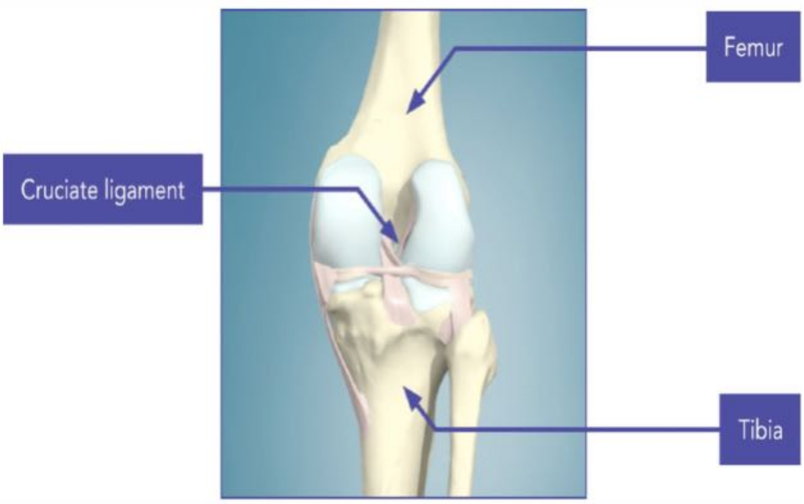
The larger of the two bones (second largest in the body) is the tibia. Its size reflects its role in weight transmission of the upper body from the femur down through the foot. The fibula is far weaker. It is completely non-weight-bearing and appears stick-like. However, it does have a role in bracing the tibia and giving the lower leg a stout, rectangular profile rather than a curved cylinder, thus improving its strength. The fibula also provides attachment points for muscles.

The tibia alone articulates with the femur at the knee and it has a large smooth depression that accepts the femoral condyles to form the knee joint - the most complex joint in the body. It is a hinge joint allowing movements of flexion and extension in the sagittal plane.

The synovial joint cavity has many pouch-like projections called bursa. These bursae help to prevent friction between the bone and a ligament or tendon and between the skin and the patella. The articular cartilage is reinforced with lateral and medial cartilaginous C-shaped wedges called menisci. The menisci help to stabilise the joint by preventing lateral displacement of the bones.

The medial and lateral collateral ligaments also have a key role in preventing lateral displacement of the knee. The medial ligament attaches to the medial aspects of the femur and tibia; and the lateral ligament attaches to the lateral aspects of the femur and tibia.

The joint is held together internally by two sets of cruciate ligaments at both the front and back of the joint (forming a cross). The cruciate ligaments help to add further stability to the knee joint. The posterior cruciate ligament (PCL) helps to prevent unwanted posterior movement of the tibia in relation to the femur; whilst the anterior cruciate ligament (ACL) helps to prevent unwanted anterior movement of the tibia in relation to the femur. It is the ACL that is more commonly injured.




The anterior of the joint capsule is missing. However, the patella, a sesamoid shaped bone that has developed inside the tendon of one of the main thigh muscles, crosses the front of the joint and protects the knee. The patella tracks in a deep groove (patella fossa) formed in between the articulating condyles of the femur. It is held in place by strong ligaments that ensure smooth tracking over the surface of the knee joint during movement. The patellar ligament is technically an extension of the muscle tendon.

**Knee joint injuries**

When the leg is fully extended, all of the ligaments are taut and the menisci are compressed, so that any rotational movement is prevented. A blow to the lateral side of the knee in this position - very common in team sports such as football - has a high risk of tearing the medial collateral ligament and its attached meniscus, as well as the relatively weak ACL.

To allow flexion, the lateral and medial ligaments need to relax. However, this means that the joint is far less stable and the tibia can move freely on the femur - laterally and medially as well as forward and back. This is unlikely to cause problems when the knee joint is not loaded during flexion, although care must be taken to ensure that rotational movement is minimised.

When the joint is bearing full body weight in a flexed position (eg, during a lunge), the risk of damage to joint structures is extremely high. This move is often used as a strength exercise for the thigh muscles but demands a high level of body awareness and technical skill, particularly when weight (eg, free weights) is being used in addition to body weight. To prevent any unwanted lateral movement or rotation exceptional observational and correctional skills are needed from the instructor.

**The ankle joint and foot**

The foot follows the same principles as the hand. The tarsal bones - like the carpals of the hand - are roughly cuboid and articulate with each other via gliding synovial joints. There are seven tarsals, but the two largest ones, nearest to the lower leg, mainly carry body weight.

These are:

- the talus bone that articulates with the tibia and fibula
- the large calcaneus, or heel bone, on which the talus sits.

The calcaneus makes contact with the ground and provides the attachment point for the large, long tendon of the calf muscles.

The synovial joint between the talus and the tibia and fibula is a pure hinge joint: its movement is restricted to plantar and dorsiflexion in the sagittal plane. It is the gliding joints between the talus (subtalarjoint), the calcaneus and all of the other tarsal bones that give the whole foot the flexibility to walk or run on uneven surfaces by allowing inversion and eversion movement. Excessive eversion or inversion moves can cause damage to the ligaments or fracture the bone. The lateral ligaments on the outside of the foot are particularly susceptible to inversion damage as they are weaker than the medial ligaments.

The metatarsals are five bony cylinders, corresponding to the metacarpals of the hand. The first and fifth metatarsals make contact with the ground and are strong weight bearers. The remaining three, however, form a transverse arch and are susceptible to fracture.

The phalanges complete the pattern. Again like the fingers, they have three segments (apart from the big toe, which has two), but they are much smaller than in the fingers and therefore do not exhibit the same range of movement. The arches of the foot give it its considerable strength, weight-bearing capacity and 'springiness'. The semi-dome of the underside of the foot is maintained by many ligaments and by the tension of muscle tendons.

**Key points for the skeleton**

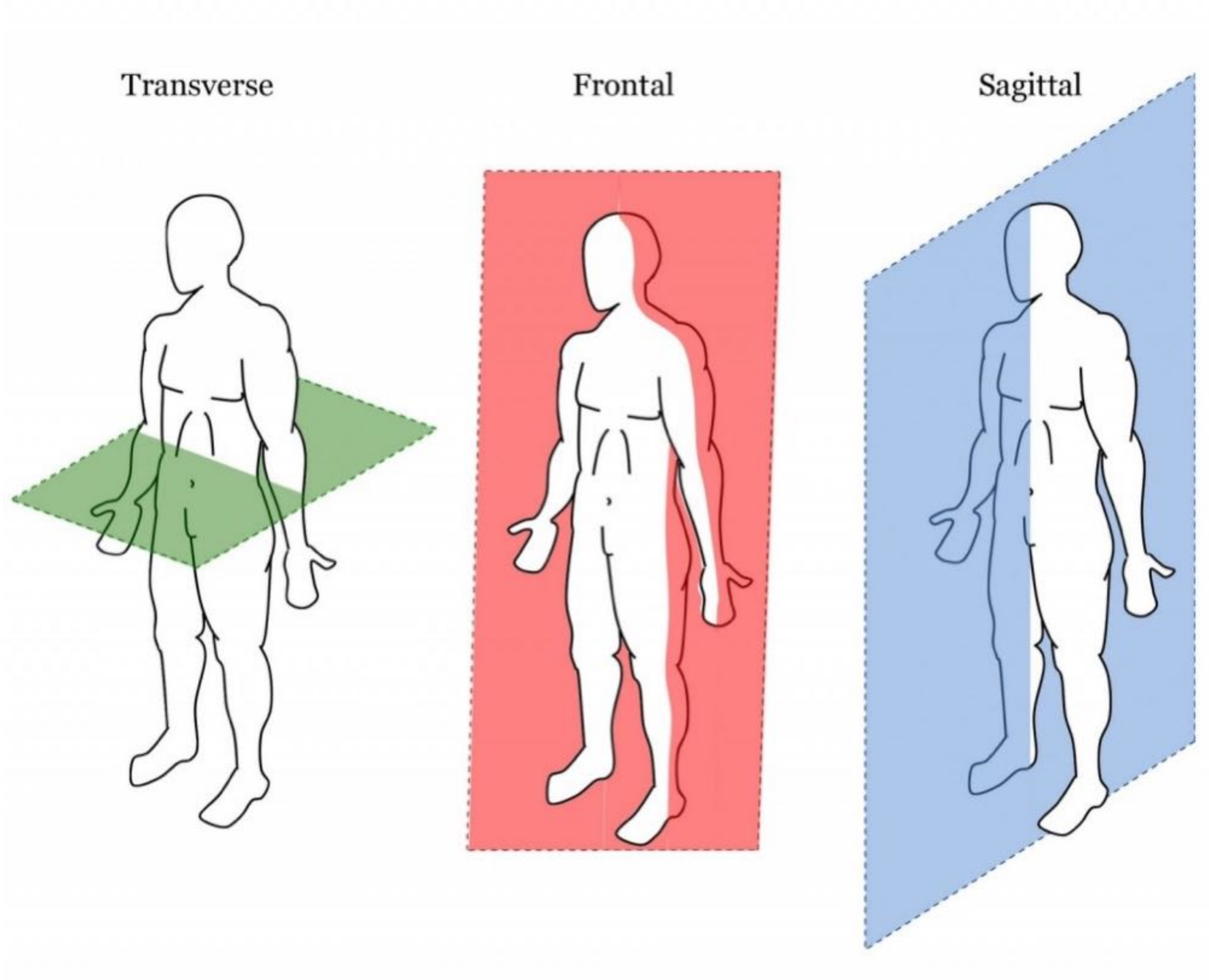
- The skeleton is divided into two parts: the axial skeleton (skull, ribs and spine) and the appendicular skeleton (upper and lower limbs, and the bones of the shoulder and hip girdles).
- The main functions of the skeletal system are movement, shape, protection, mineral storage and blood cell production.
- Joints connect bones and are held together by connective tissue, which is vulnerable to hormonal influences during pregnancy and the menopause.
- The spine is a flexible column of 33 individual bones, comprising 7 cervical, 12 thoracic, 5 lumbar, 5 (fused) sacral bones and 4 (fused) coccygeal bones.
- Normal cervical, thoracic and lumbar curvatures of the spine are affected by genetics and lifestyle factors, which can exaggerate the curve.

### Anatomical planes

When the human body is scientifically examined, it is divided into sections, depending on the plane of dissection. Anatomists use a variety of terms to describe these planes. The main ones are:

- The frontal or coronal plane, which separates the body into front and back sections (anterior and posterior)
- The sagittal plane, which separates the body into left and right sections, although they can be uneven (the slice may be more to the right than the left). If it is directly down the centre it is called the median or mid-sagittal plane
- The transverse (or horizontal) plane which separates the body into upper or lower parts.

Referencing the anatomical planes may help to clarify some of the terminology used when discussing body movements, muscle actions, or the names and locations of muscles.



**The transverse plane**
Any movement that rotates the body (or part of the body) is in the transverse plane eg, rotation of the spine or shoulder.
A muscle with the word 'transverse' in front of it will wrap around the body, such as the transverse abdominis.
Exercises that occur in the transverse plane include waist rotations, oblique twists, and medial and lateral rotation of the shoulder joint to strengthen the rotator cuff muscles.

**The frontal plane**
Any movements that go out to the side away from the body (abduction) and back in towards the middle of the body (adduction) are in the frontal plane.
Exercises that occur in the frontal plane include lateral raises, side bends, standing hip adduction and abduction.

**The sagittal plane**
Any movement that brings a body part in front of or behind the body (eg, a swinging motion of the leg or arm) is in the sagittal plane, ie, the movements that occur in this plane are flexion and extension.
Exercises that occur in the sagittal plane include bicep curls, leg extension etc.

**Additional information**

Familiarity with planes of movement is useful when planning a balanced training programme. Many popular exercises are ones where the limbs move forwards and backwards: squats, pushing and pulling, etc. These mainly occur in the sagittal plane.

Then there are common exercises where limbs move sideways in the frontal plane: lateral raises, side leg raises etc. However, there are fewer common exercises in the transverse plane. Instructors need to think about: How many rotational exercises do they perform themselves in their own regular routine?

This bias towards sagittal/frontal plane exercises could be argued to be unbalanced and create a functional weakness, especially when so many everyday activities and sporting movements naturally involve rotation. A good question for an instructor to ask themselves when planning a balanced approach to strengthen the body is: Have I included exercises in all three planes of movement?

Transverse plane movements can be performed easily using cables, or using weights like kettlebells and medicine balls that can be moved freely in different directions. Exercise performed from an unstable base such as a Swiss ball can also be useful for introducing some rotational challenge.

In addition to the planes, anatomists have other accepted terms to allow us to explain where one body structure is in relation to another. This is always assuming the body is in the anatomical position.

| Directional term | Explanation |
|---|---|
| **Superior** | Towards the upper part of a structure (above) |
| **Inferior** | Towards the lower part of a structure (below) |
| **Anterior** | At the front of the body |
| **Posterior** | At the back of the body |
| **Medial** | Towards the midline of the body |
| **Lateral** | Away from the midline of the body |
| **Proximal** | Closer to the origin or point of attachment |
| **Distal** | Further away from the origin or point of attachment |
| **Unilateral** | On one side of the body |
| **Bilateral** | On both sides of the body |
| **Superficial (global)** | Nearest to the surface |
| **Deep (local)** | Further away from the surface |

For example, the terms medial and lateral are used to describe the sides of a sagittal plane on which a muscle (or any structure) can be found. Medial muscles, such as vastus medialis in the quadriceps group in the front of the thigh, are always nearer the middle of the body or plane. Lateral muscles, such as vastus lateralis in the same muscle group, are always further away from the middle of the body or centre of the plane. Anterior and posterior are used to describe the sides of a frontal plane, for example the deltoids.

## Joints

Joints form the connection between bones. A joint, or articulation, occurs where a bone meets a bone and are connected and held together by connective tissue.

## Connective tissue

Ligaments - these attach bones to bones. Ligaments play a key role in stabilising joints. Over stretching of the ligaments is described as a ‘sprain’.

Tendons - these attach muscles to bones. Over stretching of muscles and tendons is described as a ’strain'.

## Cartilage

Cartilage lines the ends of the bones in the joint area and prevents them from rubbing against each other and wearing bones down. Cartilage also provides shock-absorption, particularly in the lower limb joints.

Note: It should be noted that hormonal influences during pregnancy and the menopause have an effect on connective tissue.

The joint is given stability by a number of factors, including the joint capsule, the surrounding ligaments whose job is to bind bone with bone and the nearby muscles and tendons.

A sound understanding of joint structure, as well as the factors that influence joint mobility, is essential for the practice of safe and effective exercise.

## How the components fit together

When a muscle contracts (shortens), it pulls on the tendon attached to the bone and creates movement. If humans didn't have skeletons, our bodies would be just blobs of muscle and fat and we would be unable to move.

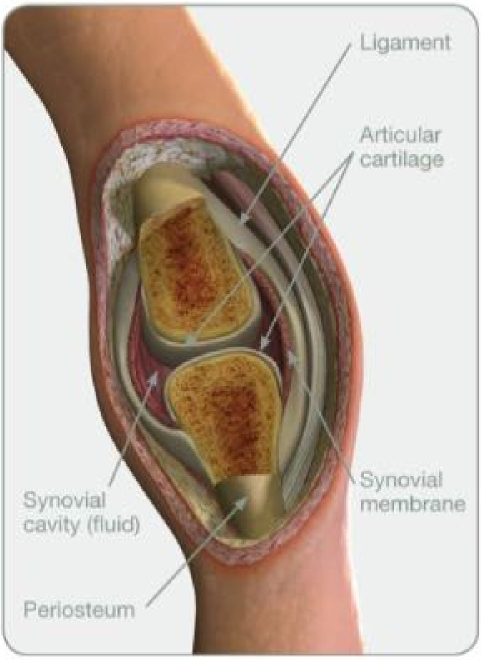
Joints come in three basic types:

1. **Immovable (fibrous) joints** - where bones are joined together by fibrous connective tissue. An example of this type of joint are the bones of the skull, which are given added connective strength by the dove-tailed edges.

2. **Slightly movable (cartilaginous) joints** - where the bones are tightly connected by cartilage or fibrous cartilage. Good examples of this type of joint are the connections between the vertebrae and also the pubis symphysis, which joins the two halves of the pelvic bones.

3. **Freely movable (synovial) joints** - where the ends of the bones are covered with cartilage and are connected by a fibrous capsule. Inside the capsule is a synovial membrane. This is the most common type of joint, and examples include the hip and shoulder joints.

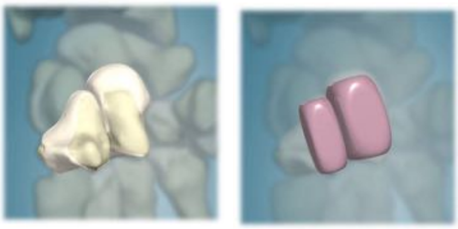
## Synovial Joints




As synovial joints are the joint type you will come across most, it is important to explore this joint type in more detail.

A synovial joint is surrounded by a sleeve-like capsule (referred to as the 'joint capsule') that encloses the joint cavity and is attached to the outside of the bone (periosteum). The inner layer of the joint capsule is formed by a synovial membrane, which secretes synovial fluid. This fluid helps to lubricate the joint and provides nourishment for the articular cartilage on the ends of the bones. Cartilage is a tough, smooth tissue that helps to reduce friction between the bones and provides shock-absorption to the joint.

**Types of synovial joints**
There are six types of freely moveable (synovial) joints:

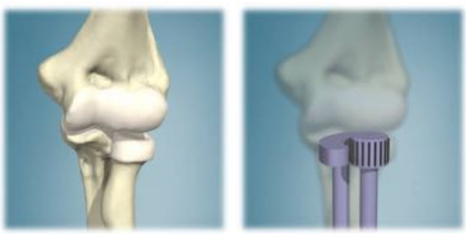


**Gliding Joints**

Where movement is over relatively flat surfaces, for example - carpals, tarsals and the AC Joint.

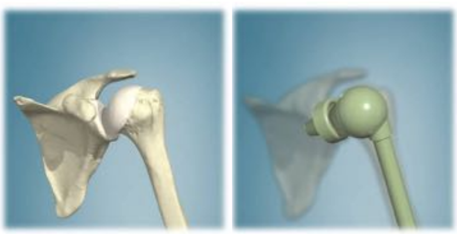
**Hinge joint**

Where movement is possible in one plane only, i.e. the elbow or knee.



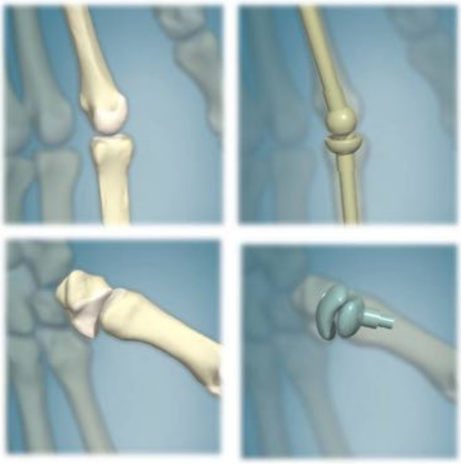
**Pivot Joint**

Where movement is purely rotational, i.e. the articulation of the radius and ulna to allow the body to pronate and supinate the forearm as the bones rotate around each other.



**Ball and Socket Joint**

Where movement occurs in three dimensions, i.e. the hip and shoulder joints.



**Condyloid Joints**

Where movement occurs in two planes, i.e. in the wrist between the ulna, radius and carpals.

**Saddle Joints**

Similar to a condyloid joint but the surfaces are concave and convex, i.e. the base of the thumb.

**Special populations and joints**

**Children**
Growing bone is not completely ossified until early adulthood, making it vulnerable to damage. Common fractures and tears can occur through heavy, strenuous or highly repetitive exercise. These could not only affect the growth and development of the bone, but also the stability of the joints.

**Pregnancy**
It should be noted that during pregnancy the effects of the hormone relaxin will have a significant effect on the stability of synovial joints. Joints will have a greater range of movement than normal and will be less stable. The less stable joint combined with a decrease in motor skills (caused by a change in the centre of gravity) will necessitate an avoidance of high-impact and quick-twisting movements. It should be noted that many of the physiological changes of pregnancy can remain for up to six months after childbirth. It is therefore advisable to re-introduce regular, more vigorous training gradually.

**Ageing**
With age, changes occur in the bones, joints and connective tissue. Decreasing levels of the hormone oestrogen (in females) and increased inactivity can both affect bone remodelling. The articular cartilage becomes thinner. Changes to the synovial membrane occur and secretion of synovial fluid, which lubricates the joint, diminishes. Ligaments tend to shorten and lose some flexibility. Tendons become weak, less elastic and lose their ability to withstand excessive stress. Overall, joints become stiffer and less flexible with age. It should be noted that one of the key long-term joint adaptations to exercise is an increase in the strength of ligaments and tendons, which can help to offset these inevitable changes.

**Disability**
Individuals with disabilities may have limitations specific to their disability, and these should be carefully considered prior to exercising.

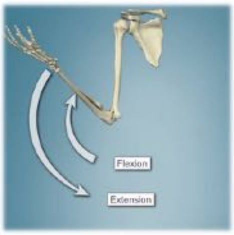
**Key points of joints**

- There are three basic types of joint: immovable/fibrous, slightly moveable/cartilaginous and freely movable/synovial.
- Synovial joints comprise: a joint capsule, synovial membrane, synovial fluid and articular cartilage.
- There are six types of synovial joint: gliding, hinge, pivot, condyloid, saddle, and ball and socket.
- Long-term exercise can increase the strength of ligaments and tendons, thereby making the joint more stable.
- There are specific changes to the joints that should be considered for special populations.

**Joint Actions**

To perform exercise in a safe and effective manner, it is important to understand what movements are possible at specific joints. Joint movements are determined from the standard anatomical position. This position is assumed when standing erect with the feet and palms facing forwards and arms at the side.

For most movements, there is a corresponding opposite movement (e.g flexion decreases the angle at the joint, while extension increases it).




**Flexion and Extension**

Flexion reduces the angle at the joint, e.g. bending the arm at the elbow.
Extension returns from flexion, increasing the angle at the joint, e.g straightening the arm at the elbow.
It occurs in a sagittal plane.


**Elevation and Depression**

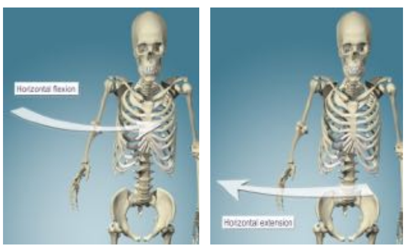
Elevation lifts or raises a joint, such as lifting the shoulders.
Depression drops or lowers the joint, such as dropping the shoulders.
It occurs in a frontal plane.


**Abduction and Adduction**

Abduction takes away from the midline of the body, e.g raising the arm or leg away from the body.
Adduction brings towards the midline of the body.
It occurs in a frontal plane.


**Lateral Flexion and Lateral Extension**

Lateral flexion is to bend sideways with the trunk or neck.
Lateral extension is to straighten back from a sideways bending position.
It occurs in a frontal plane.




**Horizontal Flexion and Horizontal Extension**

Horizontal flexion is a forward movement in a horizontal plane, e.g drawing the arm across the body as in a fly exercise.
Horizontal extension is a backward movement in a horizontal plane, e.g swinging the body away from the body.
The movement works through a transverse plane of movement.


**Pronation and Supination**

Pronation is to turn the palm down.
Supination is to turn the palm up.
It occurs in a transverse plane.


**Plantar Flexion and Dorsi Flexion**

Plantar flexion is to point the toes away from the body, e.g standing calf raise. Dorsi flexion is to pull the toes towards the body, e.g digging the heel in the ground.


**Protraction and Retraction**

Protraction is drawing the shoulder forwards, rounding the shoulders. Retraction is drawing the shoulders back, pulling the shoulder blades close together.


**Rotation**

A rotary movement, e.g turning the thoracic spine to the side as in trunk twists. This is turning of a bone around its own axis in the transverse plane. Turning the head at the neck is an example of this. It is also possible to rotate ball and socket joints. For example, turning the leg inwards towards the midline of the body (internal or medial rotation).


**Circumduction**

Circular movement of the body, e.g with the arm. This is moving a limb so that it describes a conical shape in space. This is possible at ball and socket joints, and to a lesser degree at condyloid joints.

**Opposition**
This describes the specific movement of touching the thumb to the fingers. It is what makes humans unique from other animals in their ability to grip objects.

**Eversion and Inversion**
These movements occur at the foot (specifically at the subtalar joint) in the transverse plane. Inversion is where the sole turns to face inwards, and eversion is where the sole turns to face outwards.This movement capacity allows us to adapt to running on rough surfaces such as grass or gravel. The foot ‘gives’ or rolls with the terrain.

**Hyperextension**
This is extension beyond the anatomical position. It occurs in the sagittal plane.

**Bone**

Bone is a type of connective tissue. Connective tissue comes in all sorts of shapes and sizes. It is defined as a tissue that connects, supports, binds or separates other tissues or organs.  The main types of connective tissue are:

- bone - bone has a compact part in the middle and a spongy part at the ends
- connective tissue (such as ligaments and tendons) - the collagen fibres that make up these structures are well organised and can withstand a lot of force
- cartilage - there are different types of cartilage. The cartilage that lines the end of the joints is a network of fibres, tougher than those of ligaments and tendons and they are embedded in a gel-like substance that also makes them good at absorbing shock
- blood - strange though it might seem, blood is also a type of connective tissue
- lymph - a type of connective tissue that is an important part of the immune system circulating disease-fighting cells.

**Types of bone**

**Long bones**
Long bones have greater length than width and are slightly curved for strength, which helps to absorb the stress of the body. Examples of long bones include the femur and tibia.

**Short bones**
Short bones are somewhat cube-shaped and nearly equal in length and width. Examples include the carpals (wrist).

**Irregular bones**
Irregular bones have complex shapes. Examples include the bones of the spinal column and certain facial bones.

**Flat bones**
Flat bones are generally thin and afford considerable protection for internal organs and extensive areas for muscle attachment. Examples include the pelvis and sternum.

**Sesamoid bones**
Sesamoid bones are bones that are embedded in a tendon. Examples include the patella.

**Bone growth**

Bone is a living tissue with its own blood supply and is constantly being reshaped and remodelled.

**Birth to age 25 (approximately).**
When a human being is conceived, groups of cells crowd together in the shape of a bone and secrete a cartilage matrix. Just eight weeks after conception, the main bones have already formed in cartilage and connective tissue membranes. In the middle of these cartilage 'bones', some of the cells expand in size and then burst. The cell contents stimulate the cartilage on the outside to turn into bones. This makes it harder for nutrients to get into the bone, causing the cells inside to start to die and form small cavities in the middle of the bone.
A nutrient artery penetrates the bone, bringing blood and nutrients into the disintegrating cartilage (nutrients such as calcium give the bone resilience, and magnesium gives the bone its hardness). These nutrients 'wake up' the bone-building cells (osteoblasts), which start laying down a bone matrix over what is left of the cartilage.
As the process continues to the end of the bone, bone-clearers, called osteoclasts, start to clear up this matrix in the middle of the bone, creating a cavity for bone marrow. They achieve this thanks to an epiphyseal plate (growth plate), which is a highly active area of cartilage and bone manufacture.
There is an epiphyseal plate at each end of the bone. This plate is surrounded by several active cells. On one side of the plate (nearest the end of the bone), cartilage is constantly being produced. On the other side of the plate (the one nearest the centre of the bone), osteoblasts are laying down bone matrix on top of this cartilage. This whole process just keeps moving forwards, with calcified bone being cleared up by the osteoclasts behind and the osteoblasts constantly building new bone over the new cartilage. The result is that the bone is continually growing. Long bones continue to grow until around age 18 but keep maturing until approximately the age of 25. The epiphyseal plate then fades, leaving a bony structure called the epiphyseal line. When this line appears, it shows that the bone has stopped growing.
This process is known as ossification.

**Remodelling**
Throughout our lives, osteoclasts (bone-clearers) remove old bone and osteoblasts (bone-builders) lay down new bone tissue. Bone growth, development and remodelling are dependent on the balanced action between these two cells. Weight-bearing physical activity is a very important part of this process because the bones respond to the pulling effects of the muscles by laying down new bone. This means that the body is very cleverly and constantly adapting to its needs.
Long periods of non-weight-bearing activity, as in older age or periods of inactivity due to a fall or injury, mean that the bone is not being stimulated to lay down new bone, and therefore can become more fragile.
As weight-bearing activity is the key to this process, activities such as swimming and cycling, in which the body is supported by the water or bicycle, are less effective.

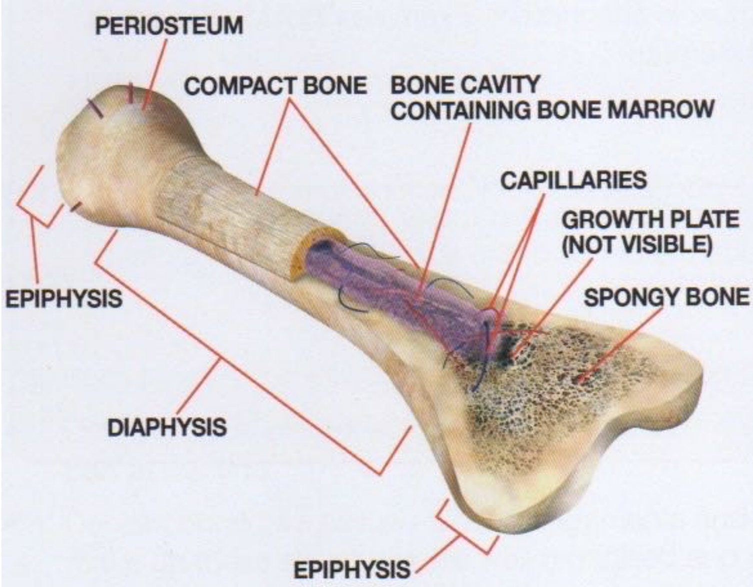
**Factors affecting bone growth and remodelling**

**Growth spurts**
Growth spurts are times when bone growth quickens due to an increase in hormonal activity. Growing pains are often experienced at this time, as muscles, ligaments and tendons are a little slower to adapt to the changes in size. Co-ordination can also be affected at this time, as a child may have biomechanical problems adapting to their change in size. The significance of this is that growing bone is vulnerable to damage. Excessive exercise of the wrong type in childhood can therefore be very damaging to the development of the skeleton.

**Older age**
As we get older, minerals tend to be lost in the bones and we may start to suffer from a degenerative process called osteoporosis, in which the bones begin to get thinner and more fragile. One of the main causes of osteoporosis is a reduction in the amount of the hormone oestrogen in the body, which can lead to bone demineralisation, or osteoporosis.

**Diet**
Calcium has a vital role in the body, as it is used, among other purposes, in muscle contractions and sending of nerve signals around the body. When calcium levels drop in the body, this is instead taken from the bone, which may result in a weakening of the bone. It is therefore essential that adequate levels of calcium are included in the diet. Vitamin D is also needed, as without it, calcium cannot be absorbed into the body.

**Bone structure**




A long bone comprises:

- diaphysis - shaft of the bone, made of compact bone, dense and very strong
- periosteum — a hard, protective fibrous sheath around the bone (but not over the ends). It contains a rich supply of blood vessels that brings nutrients for bone cells and takes away waste matter
- Epiphysis - the ends of the bone made of cancellous, or spongy, bone tissue designed to withstand compression forces
- epiphyseal plates (growth plates) - these separate the shaft from the ends of the bone. These are the areas of growing tissue in children and adolescents and are the weakest areas of the growing skeleton. When growth is complete, the growth plates close and are replaced with solid bone. They remain vulnerable to damage until this time
- medullary cavity (middle of the bone) - this contains bone marrow (site of production of red and white blood cells)
- capillaries — supply blood to all parts of the bone
- articular cartilage - covers the top of each epiphysis. It is tough, smooth and helps to reduce friction between the bones, as well as providing shock absorption for the joint.

Including weight-bearing exercise as part of a programme for those vulnerable to bone thinning (such as the older adult, after periods of inactivity and those with disabilities) can increase bone density and offset some of the bone changes that come with old age and other conditions. It is worth noting that osteoporosis can also occur in girls, particularly if they have inadequate nutrition or overtrain, which can cause them to miss menstrual cycles.

## Key points of joints

- There are various types of bone, including: long, short, flat, irregular and sesamoid.
- Bone growth results from a process called ossification, which is not completed until around the age of 25.
- Bone remodelling happens throughout life. It is stimulated by weight~bearing activity and affected by several factors, such as growth spurts, older age, diet, hormonal status, injury and disability.
- Long bones have a diaphysis, periosteum, epiphysis, epiphyseal plates, medullary cavity capillaries and articular cartilage.
- Regular weight-bearing activity can increase bone density and help to offset the natural decrease in bone density that occurs with age.

# The Muscular System

As a fitness professional, it is important to have an understanding of a muscle's action on a joint. This section will explore the structure, function and joint movement brought about by muscle contractions. Knowledge of muscle function allows for the planning, performance and evaluation of safe and effective exercise.

By the end of this section, the learner should be able to:

- identify the three types of muscle tissue
- define the characteristics and functions of the three types of muscle tissue
- describe the cellular structure of skeletal muscle
- identify and locate the muscle attachment sites for the major muscles of the body
- describe the structure and function of the pelvic floor muscles 0 describe the different types of muscle action
- identify the joint actions brought about by specific muscle group contractions
- identify skeletal muscle fibre types and their characteristics
- explain the effects of different types of exercises on muscle fibre type
- describe the life course of the musculoskeletal system, including relevant tendon, ligament, muscle, joint and bone mineral density changes, and their implications for exercise, plus specific implications for working with:
    - young people in the 14-16 age range
    - antenatal and postnatal women
    - older people (50 plus).

**Overview of muscles**

It is estimated that there are up to 650 skeletal muscles in the human body, making up about 30-50% of body weight. As well as skeletal muscles, there are also other types of muscles within the body that are just as important to maintain body functions.

**Types of muscle**

There are three types of muscle that can be found around the body. The three types of muscle are involuntary, voluntary and cardiac.

**Involuntary muscle**
Involuntary muscle is also known as visceral or smooth muscle. Similar to cardiac muscle, it contracts under unconscious control. It contracts in response to stimulation by nerves or chemicals, such as hormones, which circulate around the body. Examples of involuntary muscles can be found in the urinary and respiratory systems and the gastrointestinal tract.

**Voluntary muscle**
This is the type of muscle encountered most frequently during exercise. It is also known as striated, striped or skeletal muscle because it is attached to the skeleton. This type of muscle is under our conscious control, hence the term 'voluntary' muscle. It is stimulated by the nervous system and when the muscles contract they shorten and create movement on the bones to which they are attached. Examples of voluntary muscles include the biceps and quadriceps.

**Cardiac muscle**
Cardiac muscle is a type of involuntary muscle found in the walls of the heart. However, unlike other involuntary muscles, it is striated. It is stimulated by electrical patterns that create a co-ordinated contraction of the heart muscle to propel blood out of the heart and around the body. Although it is classified as involuntary, it has a different structure to other involuntary muscle cells found in the urinary, respiratory and intestinal tracts.

**Muscle function**
Muscles have four main functions:

**Producing movement**
Skeletal muscle is attached to the skeleton; therefore, when a muscle contracts, it brings about movement of the body. This helps us to carry out our day-to-day activities and exercise.

**Stabilising the body**
The contractions of the skeletal muscle help hold the body in a certain position, such as when we are standing or sitting still.

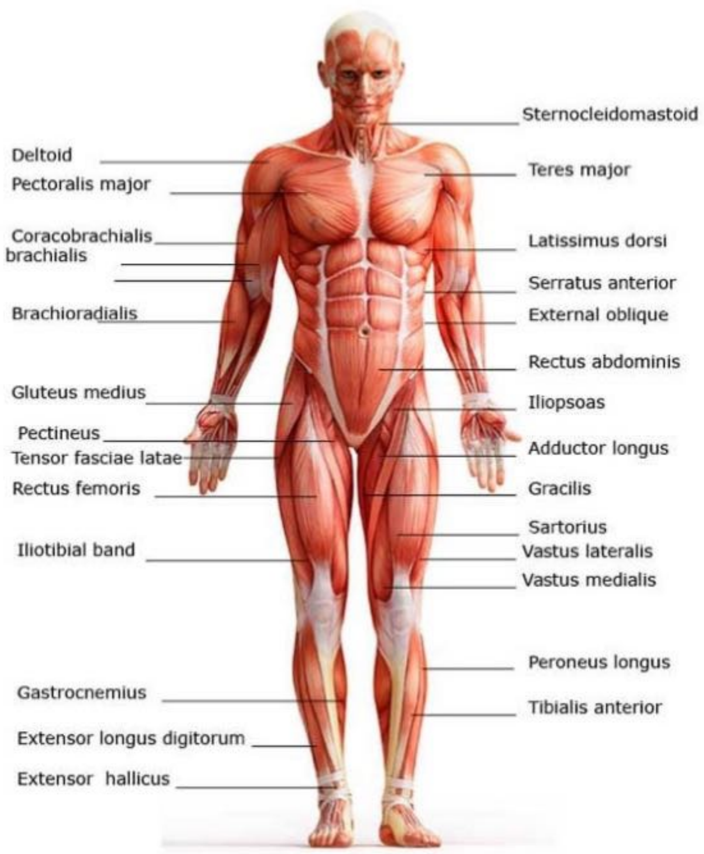
**Storing and moving substances within the body**
Cardiac muscle helps to move blood around the body. Other types of involuntary muscle can be found in the walls of blood vessels and the gastrointestinal tract, where smooth muscle will push food and substances through the digestive system.

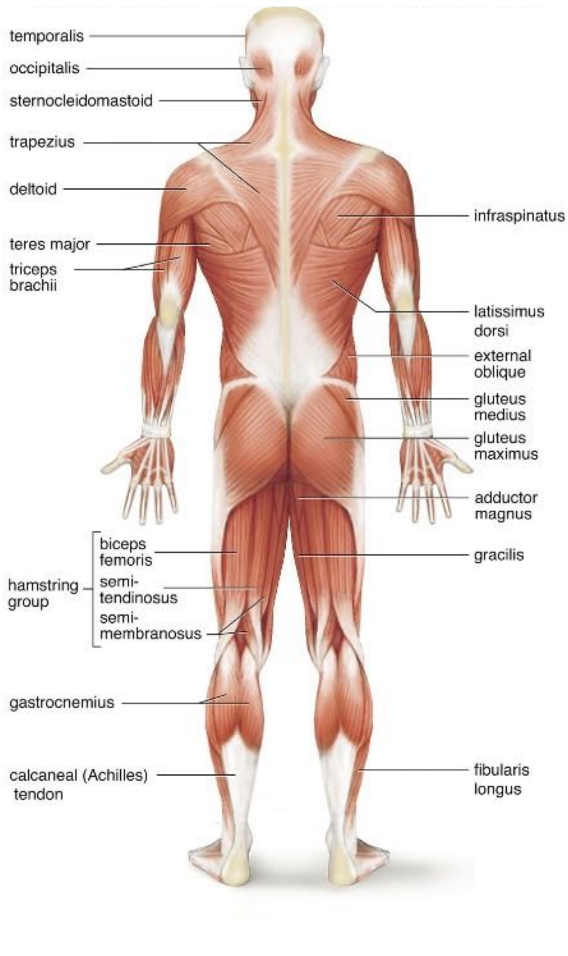
**Generating heat**
The heat generated by muscle is used to help maintain body temperature. For example, shivering is a series of involuntary contractions of skeletal muscle that significantly increases the rate of heat production.

**Major muscles of the body**

There are over 600 skeletal muscles in the body. However, it is only necessary to be familiar with a small number of these in order to design safe and effective exercise programmes.

Over this sections we will look at the origin (start) and insertion (finish) of each muscle in anatomical detail. This is perhaps the most technically complex aspect of the entire course. At the same time, it is also the most important and useful information needed to write effective programmes for clients. The name of individual muscles can often give a lot of information about their shape (eg, trapezius, rhomboid), their location (pectorals), their size (maximus, minimus, longus), the number of divisions or insertions (biceps, triceps, quadriceps), or even the direction of their muscle fibres (transversus, oblique, rectus (upright).



## Muscles of the Shoulder/Pectoral Girdle

**Trapezius**
Origin: Back of cranium and all thoracic vertebrae
Insertion: Spine of scapula and lateral edge of clavicle
Joints crossed: Shoulder girdle
Joint actions: Upper fibres - Elevates shoulder girdle
Middle fibres - Retracts shoulder girdle
Lower fibres - Depresses shoulder girdle

**Levator scapulae**
Origin: Transverse processes of cervical vertebrae (C1-C4)
Insertion: Medial border of scapula, between superior angle and root of spine of the scapula
Joints crossed: Shoulder girdle
Joint actions: Origin fixed - Elevates the scapula. Assists in downward rotation of scapula
Insertion fixed - Laterally flexes the neck

**Rhomboids**
Origin: Spinous processes of cervical and thoracic vertebrae (C7 and T1-T5)
Insertion: Medial border of scapula
Joints crossed: Shoulder girdle
Joint actions: Retracts and downwardly rotates scapula

**Pectoralis major**
Origin: Clavicle, sternum and cartilage of ribs 1-6
Insertion: Top of humerus
Joints crossed: Shoulder (glenohumeral) joint
Joint actions: Shoulder horizontal flexion, adduction and medial rotation

**Pectoralis minor**
Origin: Front of ribs 3-5
Insertion: Coracoid process of scapula
Joints crossed: Shoulder girdle
Joint actions: Origin fixed - Protracts scapula
Insertion fixed - Elevates ribcage during breathing

**Latissimus dorsi**
Origin: Via thoracolumbar fascia, spinous processes of T6-T12, lumbar & sacral vertebrae and iliac crest. Also lower 3-4 ribs and inferior edge os scapula
Insertion: Top of anterior humerus
Joints crossed: Shoulder (glenohumeral) joint
Joint actions: Origin fixed - adducts and extends arm, assists in medial rotation. Also depresses the shoulder girdle via insertion on the humerus
Insertion fixed - Tilts the pelvis forwards

**Deltoid**
Origin: Anterior head - Clavicle
Medial head - Acromion process of scapula
Posterior head - Spine of scapula
Insertion: Lateral surface, half-way down, humerus
Joints crossed: Shoulder (glenohumeral) joint
Joint actions: Anterior fibres - Flex shoulder and assist in horizontal flexion and medial rotation
All fibres abduct the shoulder with emphasis on medial fibres
Posterior fibres- Extends shoulder and assist in lateral rotation

**Serratus anterior**
Origin: Front of ribs 1-8
Insertion: Anterior surface of medial border of scapula
Joints crossed: Shoulder girdle
Joint actions: Protracts and upwardly rotates scapula

**Teres Major**
Origin: Lateral border of the scapula, near the inferior angle
Insertion: Humerus - Proximal and anterior
Joints crossed: Shoulder
Joint actions: Medial rotation, adduction and extension of the shoulder joint

## Muscles of the Shoulder/Pectoral Girdle - The Rotator Cuff Muscles

**Supraspinatus**
Origin: superior to spine of scapula
Insertion: Superiorly on the head of the humerus
Joints crossed: Shoulder
Joint actions: Assists deltoid in abduction of the arm. Weak lateral rotator

**Subscapularis**
Origin: Anterior surface of the scapula
Insertion: Anteriorly on the head of the humerus
Joints crossed: Shoulder
Joint actions: Rotates arm medially

**Infraspinatus**
Origin: Inferior to the spine of scapula
Insertion: Laterally on the head of the humerus
Joints crossed: Shoulder
Joint actions: Rotates arm laterally

**Teres minor**
Origin: Lateral border of scapula near inferior angle
Insertion: Laterally on the head of the humerus
Joints crossed: Shoulder
Joint actions: Rotates arm laterally

## Muscles of the Arm

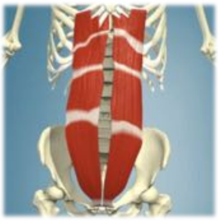
**Biceps brachii**
Origin: Scapula
Insertion: Top of radius
Joints crossed: Shoulder and elbow
Joint actions: Flexes elbow and supinates forearm. Assists in shoulder flexion

**Triceps brachii**
Origin: Long head on scapula, other two heads on posterior of humerus
Insertion: Olecranon of ulna
Joints crossed: Shoulder and elbow
Joint actions: Extension of elbow and assists in shoulder extension and adduction

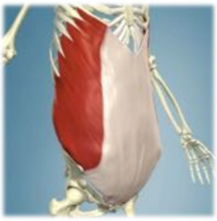
Other muscles:

| Muscle | Origin | Insertion | Primary Action |
|---|---|---|---|
| Coracobrachialis | Superior scapula | Medial humerus | Flexion and adduction of the humerus |
| Brachialis | Mid humerus | Superior ulna | Flexion of forearm |
| Brachioradialis | Distal humerus | Distal radius | Flexion and supination of forearm |
| Common wrist flexors | Medial humerus | Palm of hand | Flexion of wrist |
| Common wrist extensors | Lateral humerus | Back of hand (dorsum) | Extension of wrist |

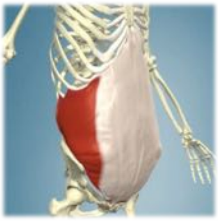
## Muscles of the vertebral column



**Rectus abdominis**
Origin: Pubis and symphysis pubis
Insertion: Cartilage of ribs 5-7 and base of sternum
Joints crossed: Intervertebral joints of lumbar and thoracic vertebrae
Joint action: Flexion of vertebral column



**External obliques**
Origin: Outer surface of bottom 8 ribs
Insertion: Mainly linea alba, also iliac crest
Joints crossed: Intervertebral joints of lumbar and thoracic vertebrae
Joint actions: Bilaterally - Flexion of vertebral column, tilts pelvis posteriorly
Unilaterally - Rotation and lateral flexion of the spine

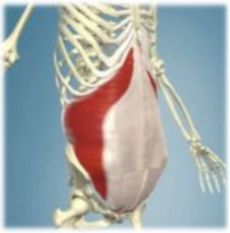


**Internal obliques**
Origin: Thoracolumbar fascia, iliac crest
Insertion: Linea alba, bottom 3 ribs
Joints crossed: Intervertebral joints of lumbar and thoracic vertebrae
Joint actions: Bilaterally - Flexion of vertebral column, tilts pelvis posteriorly
Unilaterally - Rotation and lateral flexion of the spine
Also stabilises lumbar spine by creating tension through the thoracolumbar fascia.

**Erector spinae**
Origin: Ribs and iliac crest
Insertion: Transverse processes of cervical vertebrae and ribs superior to origin
Joints crossed: Vertebrae
Joint actions: Extends the spine

**Multifidus**
Origin: Sacrum, and transverse processes of vertebrae
Insertion: Spinous processes 2-4 vertebrae superior to origin
Joints crossed: Intervertebral joints of vertebral column
Joint actions: Extension and rotation of vertebral column.
Also important to lumbar spine stability, its a ‘local’ muscle of core stability.

**Quadratus lumborum**
Origin: Iliac crest and iliolumbar fascia
Insertion: Upper 4 lumbar vertebrae and lower margin of 12th rib
Joints crossed: Intervertebral joints of lumbar vertebrae
Joint actions: Bilateral eccentric contraction - Assists in preventing hyperflexion of lumbar spine
Unilateral concentric contraction - Lateral flexion of lumbar spine
Unilateral isometric contraction - Prevents lateral flexion of lumbar spine, i.e. when carrying a heavy bag in one hand



**Transverse Abdominis**
Origin: Iliac crest, lower 6 ribs, lumbar fascia
Insertion: Linea alba and pubis
Joints crossed: Vertebrae
Joint actions: Drawing abdomen inwards

Other muscles:

| Muscle | Origin | Insertion | Primary Action |
|---|---|---|---|
| Intercostals | Ribs | Ribs | External Intercostals - Inhalation<br>Internal Intercostals - Expiration |
| Sternocleidomastoid | Sternum and medial clavicle | Mastoid process | Flexion, lateral flexion and rotation of neck |
| Scalenes | C1-C8 | 1st and 2nd ribs | Flexion, lateral flexion and rotation of neck |

## Muscles of the hip

**Gluteus maximus**
Origin: Base of spine, sacrum and coccyx, and back of ilium
Insertion: Iliotibial tract and femur
Joints crossed: Hip
Joint actions: Extends and laterally rotates hip

**Gluteus medius**
Origin: Outer surface of ilium
Insertion: Laterally on top of femur
Joints crossed: Hip
Joint actions: Abducts hip a, posterior fibres laterally rotate hip.
Also important in hip stabilisation during the support phase in walking/running, preventing the pelvis dipping and the knees rolling in.

**Gluteus minimus**
Origin: Outer surface of ilium
Insertion: Laterally on top of femur
Joints crossed: Hip
Joint actions: Abducts and laterally rotates hip
Also important in hip stabilisation during the support phase in walking/running, preventing the pelvis dipping and the knees rolling in.

**Piriformis**
Origin: Anterior surface of sacrum
Insertion: Top of femur, on the greater trochanter
Joint crossed: Hip
Joint actions: Abducts hip and assists in lateral rotation of hip. If hip is flexed it may assist in medial rotation

**Iliopsoas:**

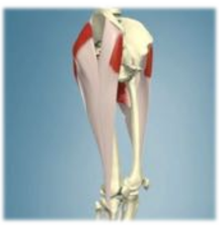
**Iliacus**
Origin: Inside surface of ilium
Insertion: Top of femur, shares tendon with psoas major
Joints crossed: Hip
Joint actions: Flexes hip

**Psoas major**
Origin: Bodies, transverse processes and intervertebral discs of all lumbar vertebrae and T12
Insertion: Top of femur, shares tendon with iliacus
Joints crossed: Hip and intervertebral joints of lumbar vertebrae
Joint actions:
- Origin fixed - Flexes hip
- Insertion fixed - Pulls on spine to increase lumbar lordosis
- Unilaterally - Assists in lateral flexion of the trunk
- Stabilises lumbar spine

**Pectineus**
Origin: Pubis
Insertion: Femur
Joints crossed: Hip
Joint actions: Adducts and flexes hip

**Sartorius**
Origin: Anteriorly and laterally on the iliac spine
Insertion: Tibia (medially)
Joints crossed: Hip and knee
Joint actions: Flexion and lateral rotation of the hip, flexion of the knee

**Gracilis**
Origin: Pubis
Insertion: Top of tibia, just below the knee joint
Joint crossed: Hip and knee
Joint actions: Adducts hip and assists in knee flexion (helps hamstrings)



**Tensor fascia latae**
Origin: Crest of ilium
Insertion: Iliotibial tract
Joint crossed: Hip and knee
Joint actions: Flexes, abducts and medially rotates hip

**Adductor longus**
Origin: Pubis
Insertion: Medial / posterior surface of femur
Joints crossed: Hip
Joint actions: Adducts hip

**Adductor brevis**
Origin: Pubis
Insertion: Medial / posterior surface of femur
Joints crossed: Hip
Joint actions: Adducts hip

**Adductor magnus**
Origin: Pubis
Insertion: Medial / posterior surface of femur
Joints crossed: Hip
Joint actions: Adducts hip

**The Quadricep Muscle Group**

**Rectus femoris**
Origin: Iliac spine and top of acetebulum
Insertion: Font of tibia via patella tendon
Joints crossed: Hip and knee
Joint actions: Flexes the hip
and extends the knee

**Vastus intermedius**
Origin: Femur
Insertion: Front of tibia via patella tendon
Joints crossed: Knee
Joint actions: Extends the knee

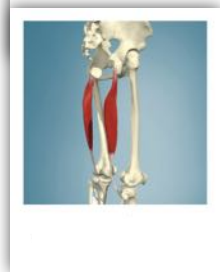
**Vastus medialis**
Origin: Femur
Insertion: Front of tibia via patella tendon
Joints crossed: Knee
Joint actions: Extends the knee

**Vastus lateralis**
Origin: Femur
Insertion: Front of tibia via patella tendon
Joints crossed: Knee
Joint actions: Extends the knee

## The Hamstring Muscle Group

**Bicep femoris**
Origin: Ischium, the short head of this muscle also sits half way down posterior surface of femur
Insertion: Head of fibula
Joints crossed: Hip and knee
Joint actions: Hip extension and knee flexion

**Semimembranosus**
Origin: Ischium
Insertion: Tibia
Joints crossed: Hip and knee
Joint actions: Hip extension and knee flexion



**Semitendinosus**
Origin: Ischium
Insertion: Tibia
Joints crossed: Hip and knee
Joint actions: Hip extension and knee flexion

## Muscles of the Lower Leg

**Gastrocnemius**
Origin: Condyles of femur
Insertion: Calcaneus via achilles tendon
Joints crossed: Knee and ankle
Joint actions: Plantar flexion and assists in knee flexion

**Soleus**
Origin: Tibia, fibula and interosseus membrane
Insertion: Calcaneus via achilles tendon
Joints crossed: Ankle
Joint actions: Plantar flexion

**Tibialis anterior**
Origin: Lateral condyle of tibia, upper half of lateral surface of tibia and interosseus membrane
Insertion: Underside of medial cuneiform bone and first metatarsal
Joints crossed: Ankle
Joint actions: Dorsi flexion

**Note: We recommend that you purchase an Anatomy poster showing both the skeletal and muscular systems. This is a great way to visually learn the anatomical locations of muscles, joints, ligaments and bones.**

**A recommended book for learning visually muscles and muscle actions in relation to weight training would be the 'Strength Training Anatomy' manual by Frederick Delavier**

## Skeletal Muscle

### Muscle action

There are four key points relating to muscle action:

1. A muscle can only pull (ie, exert a contracting force); it cannot push.
2. A muscle crosses at least one joint. This is demonstrated when the muscle contracts or shortens, bringing the bones closer together.
3. A muscle can only work in its line of fibre. For example, the biceps muscle runs up and down and will only be able to shorten and lengthen in that plane of movement.
4. Muscles work in pairs. Each muscle has an opposite muscle to allow movement to occur at the skeleton. For example, when one shortens, the other one lengthens to bring about movement.

### Muscle attachment

Muscles bring about movement because they are attached to bone in the following three ways to exert a contracting force:

- Via a tendon - tendons attach muscle to bone. For example, in a biceps curl, the biceps tendon inserts into the radius bone. To bring about muscular contraction, the biceps tendon must pull on the radius to flex the elbow joint.
- Via the fibrous tissue of other muscles called an aponeurosis - a good example of this is in the abdominals, where all the muscles attach at the front of the trunk to form the abdominal aponeurosis.
- Directly onto the bone via the muscle fascia (layer of connective tissue surrounding the muscle).

Key point:
Remember that muscles can only perform their functions by contracting and thereby 'pulling' on the various bones to produce a change in the angle at a joint. If a muscle does not cross a joint, movement cannot occur, as it is the joint that acts as the pivot or fulcrum.

### Muscle Group Actions

To bring about movement, muscles work in pairs. Notice that muscles on the front of a limb are matched by muscles at the back. For example:

- biceps (front of the arm) and triceps (back of the arm)
- quadriceps (front of the thigh) and hamstrings (back of the thigh)
- rectus abdominis (front of the trunk) and erector spinae (back of the trunk).

Muscles work by generating contractions to bring about movement. The opposite movement is generated when the other muscle contracts, returning the bone to its original position.

If this was not allowed to happen, we would only be able to move in one direction. The main muscle responsible for creating the movement is known as the prime mover, or agonist, while its opposite muscle is known as the antagonist, which relaxes in order for movement to occur. A sit-up exercise is a good example of this, as the prime mover is the rectus abdominis and the antagonist is the erector spinae.

When performing an exercise, other muscles may also join in and assist the prime mover; these muscles are called synergists. For example, when performing a leg curl, if the workload is heavy, the gastrocnemius will assist the hamstrings (prime mover) to perform knee flexion.

Muscles can contract statically to fix parts of the body to maintain a correct or stable position. When a muscle performs this function, it is called a fixator.

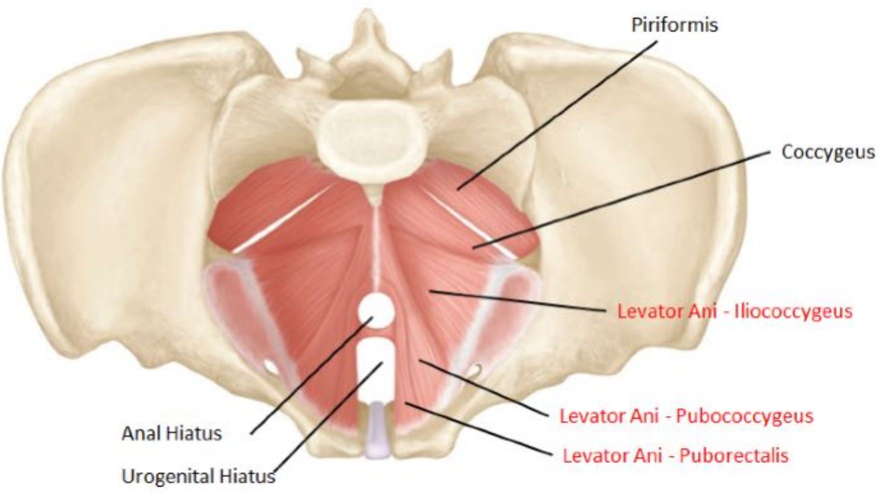
A biceps curl can be used to illustrate the different roles of the muscles and muscle groups:

- the prime mover is the biceps
- the antagonist is the triceps
- the fixator is the deltoid
- the synergist is the brachialis.

**Pelvic floor muscles**

The pelvic floor is a double-layered (superficial and deep layer) broad sling of muscle from the pubic bone at the front to the base of the spine at the back of the pelvis. Comprising: the coccygeus (deep muscle) and the levator ani (superficial muscle). It consists of both fast- and slow-twitch muscle tissue - a point that should be taken into consideration for effectively exercising these muscles.

Coccygeus and Levator Ani



The pelvic floor provides:

- stability of the pelvic girdle
- support for the organs of the pelvis and abdominal contents, as well as for the foetus when pregnant
- continence control of urine and faeces
- reflex activity to counteract changes in abdominal pressure (ie, coughing, sneezing, nose blowing, vomiting and forced expiration).

During childbirth, the pelvic floor muscles have the ability to stretch considerably to allow for childbirth. However, this can leave them weakened afterwards.

Pelvic floor muscles can become weak and sag not only from childbirth but through lack of exercise, the menopause or simply due to the ageing process. However, in the same way as one would train any other muscle group, it is also possible to train these muscles through repetition to improve and maintain their ability to effectively support the pelvis.

## Special populations and muscles

### Children

Strength naturally increases with age because of body growth and development of the neuromuscular system. However, it should be noted that the muscular system does not always develop at the same rate as the skeleton. This can make the muscular system of children susceptible to damage.

### Pregnancy

Exercise can help to relieve some of the symptoms of pregnancy. It can help a pregnant woman to carry increasing weight during pregnancy, prepare for the physical stress of labour and birth and help get the body back into shape after birth. Remember that the hormone relaxin affects the stability of synovial joints. Therefore, it is advisable to ensure that stretching exercises are limited to passive, static, short-held stretches. Supine exercises should be avoided at certain times during pregnancy, as they can reduce blood supply to the baby and mother. It should be noted that many physiological changes that occur during pregnancy can remain for up to six months after the baby is born.

### Ageing

Muscle loses size and strength as we get older, and this can contribute to fatigue, weakness and reduced tolerance to exercise. This is caused by a number of factors working in combination, including:

- muscle fibres reduce in number and shrink in size
- muscle tissue is replaced more slowly and lost muscle tissue is replaced with a tough, fibrous tissue, making it less flexible
- changes in the nervous system cause muscles to have reduced tone and ability to contract.

### Disability

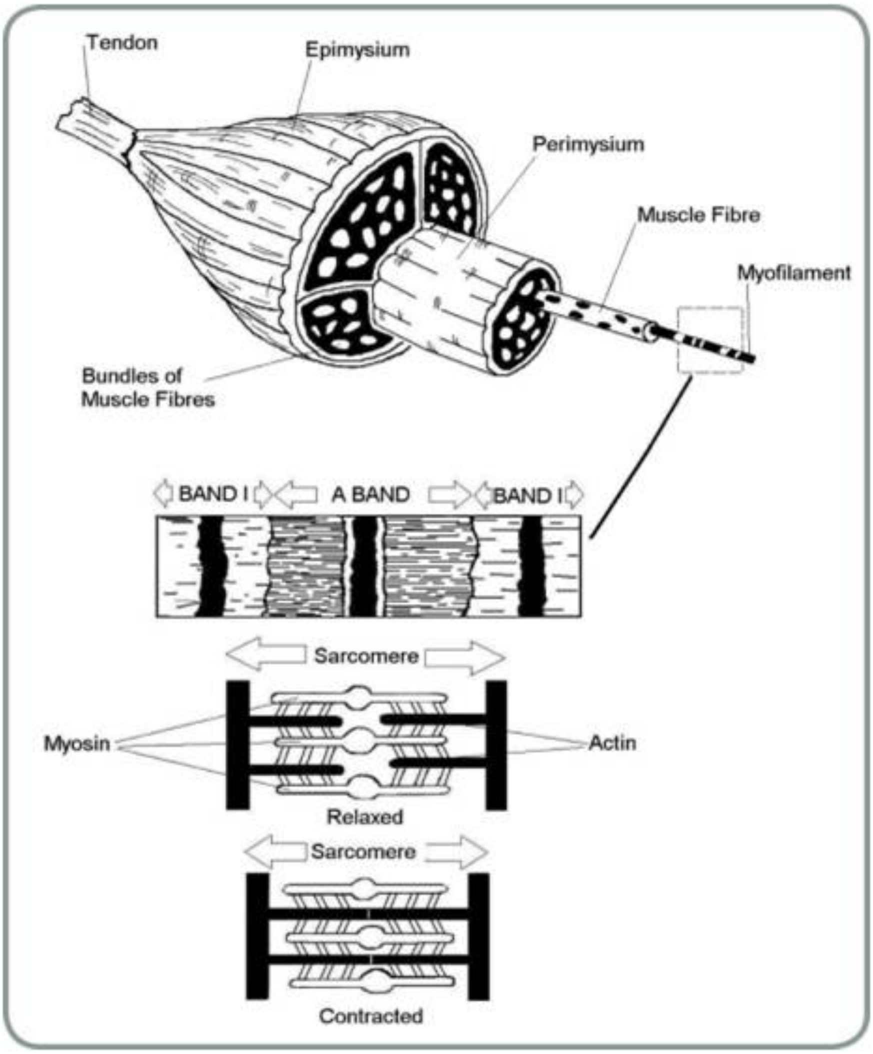
When training individuals with a disability, an instructor must consider the specific implications that the individual's disability may present in terms of their muscular system.

### Key points of muscle action

- A muscle can only pull across the joint(s) it crosses and in its line of fibre.
- Muscles work in pairs.
- Muscles attach to bone via a tendon, onto the aponuerosis of other muscles or directly onto the bone.
- Prime mover (or agonist) is the main muscle responsible for the movement.
- Antagonist is the muscle which produces the opposite movement to the prime mover.
- Fixator muscles help fix the body in the correct position to allow other movements to take place.
- Synergist muscles help the prime mover to achieve its goal.
- There are specific changes to muscles for special populations.

**Muscle Structure**

A muscle is a highly organised structure. Looking at a muscle in cross-section (see below) shows the following (large to small) components:




- Fascia - the entire muscle is surrounded by a broad protective fibrous sheath called the epimysium.
- Bundles of muscle fibres (fascicles) - muscle is composed of bundles of muscle fibres that are surrounded by another layer of fascia called the perimysium.
- Muscle fibre - each individual muscle fibre is surrounded by a thin layer of fascia called the endomysium. A single muscle fibre is composed of groups of myofibrils.
- Myofibrils - these consist of a series of thick and thin protein filaments called actin and myosin. The myosin filaments are thicker and darker in colour than the actin filaments and have small projections called cross bridges that connect to the actin. The actin filaments are thin and overlap the myosin  filaments. The arrangement of these filaments gives skeletal muscle its striated, or striped, appearance.
- Sarcomere - the smallest functional unit of a myofibril. Sarcomeres occur as repeating units along the length of a myofibril.

**Skeletal muscle**

This is the type of muscle that brings about movement of the skeleton and is largely voluntary, although there is also continuous involuntary control of postural muscles to adjust skeletal alignment.

**Skeletal muscle structure**

A muscle is a large collection of individual fibres packaged together and protected by connective tissue. This tissue is mainly composed of protein collagen fibres, with some elastic tissue.

Muscles are bound together by different fascia made of dense irregular connective tissue. This is composed mainly of collagen fibres that run in many different directions. The fasciae of the muscle eventually converge to become the tendon which will attach to the bone. The tendon is made of dense regular connective tissue. The collagen fibres in the tendon run in one direction to create a strong connection for the muscle in the direction of pull.

A sheath of endomysium surrounds each cell. The endomysium is continuous with the fibre's membrane, or sarcolemma. Many fibres are then bundled together and wrapped in the perimysium.

The bundle of fibres is referred to as the fascicle. The outer covering of the muscle then surrounds several of these bundles. This is called the epimysium. Towards the ends of the muscle the irregular collagen fibres of the fascia become more regularly aligned and thicker to form the muscle tendon. The tendon then fuses with the periosteum of the bone to which it is connected. All the connective tissues in a muscle are continuous with each other. It is this tissue that transmits the pulling forces generated inside the muscle cell to the bony levers, bringing about movement. In addition, all muscles are well supplied with blood vessels carrying nutrients and oxygen, and nerve fibres that convey the stimulus for contraction.

| Fascia | Location |
|---|---|
| Endomysium | Around each muscle cell (fibre) |
| Perimysium | Around the fascicles (bundles of fibres) |
| Epimysium | Around the outside of the muscle |

An easy way to remember the types of fascia is that the epimysium is 'epic' so the largest layer around the whole muscle; endomysium is the 'end' because it is the last and smallest layer; perimysium is simply the one in the middle.

**Muscle cell structure**

The muscle fibres (cells) are the approximate width of a human hair and often run the full length of a muscle. They are composed of smaller elements known as myofibrils. Myofibrils are divided along their length into repeating units called sarcomeres. The sarcomeres give skeletal muscle the striped or 'striated' appearance and shorten to bring about muscle contraction.

**Actin and myosin in a sarcomere**

Sarcomeres are packed with two different types of protein filaments (myofilaments); thin actin and thick myosin. Aesthetically, actin filaments look like two pearl necklaces, wound around each other. Myosin filaments are composed of collections of strands, each of which looks like a doubleheaded golf club. The myosin filaments form together, making the heads of the clubs protrude out of the surface of the filament. It is these myosin heads that make contact with the actin during muscle contraction. The myosin and actin filaments are strictly arranged inside the sarcomere to overlap each other.

**Connective tissue and collagen fibres**

Connective tissues such as epimysium, perimysium, endomysium, tendons and ligaments are composed of collagen fibres. Collagen is a fibrous protein with high tensile strength - meaning it can withstand high forces when pulled lengthwise. Collagen fibres are arranged differently according to the demands placed on the connective tissue.

**Regular collagen fibres**

These fibres run in one direction and are good at withstanding forces in one direction. However regular fibres are not strong when twisted or subjected to lateral forces.

**Irregular collagen fibres**

These fibres are found in skeletal muscles. They run in many different directions and are good at withstanding forces in different directions.

**Muscle contraction - the sliding filament theory**

When stimulated by a nerve message, the myosin heads attach to the actin molecules, forming what is known as a cross-bridge, they then pivot and bend, pulling the actin filaments over the myosin filament towards the centre of the sarcomere. The myosin heads then detach from the actin, relax back to their original positions and prepare to attach to the actin again, further down the molecule. The myosin walks along the actin, progressively pulling each filament towards the middle of the sarcomere. In this way, the muscle shortens without any change in the overall length of the myosin or actin filaments. This process happens very quickly with each of the 600+ myosin heads in a single myofibril filament attaching and reattaching about five times a second. At any one instant some of the myosin heads are attached to actin and generating force, whereas others are detached and are getting ready to bind again. This is called a contraction cycle and sometimes referred to as the 'sliding filament theory'.

Calcium is very important to the process of muscle contraction. It assists in connecting the myosin head to the actin by revealing a binding site on the actin filament. Once the binding site is revealed, the myosin can form a cross-bridge attachment. A single adenosine triphosphate (ATP) molecule is used up every time a myosin head pivots and pulls on an actin filament. For the contraction cycle to occur, muscles need a continual supply of calcium and energy in the form of ATP.

Fortunately, muscle cells carry their own store of calcium, and this is continuously being replenished from blood, which in turn will replace its reservoir from the bone (if dietary intake is inadequate). ATP needs to be re-synthesised in the muscle by the energy systems.

**Connections between nerves and muscles**

A nerve that supplies a muscle is called a motor neuron and originates in the spinal cord. As it approaches a target muscle, the motor neuron separates into a number of branches. Each of these branches goes to an individual muscle fibre, ending at the neuromuscular junction.

A single motor neuron, plus all of the muscle cells it innervates, is called a motor unit. Motor units will be detailed further in the neuro-endocrine chapter.

**Muscles fibre types**

Although individual muscle cells look very similar, they do differ in terms of two important properties:

- the speed at which they contract
- their preferred method of generating energy.

Their speed of contraction depends on both the type of motor neuron supplying them and the speed with which the fibre cells can split ATP. Faster rates here mean a greater number of contractile cycles in any unit of time. On these criteria, muscle fibres are divided into slow twitch (type I) fibres, and fast twitch (type II) fibres.

**Slow twitch fibres**

Slow twitch fibres generate their ATP predominantly in the presence of oxygen. This aerobic generation of ATP is relatively slow and the fibres are therefore called slow oxidative (SO) fibres. They have the following characteristics:

- When they are stimulated by a motor neuron to contract, slow twitch fibres do so smoothly and gradually. They take about 40-50 milliseconds (ms) to reach their maximum contraction and about the same length of time to relax again.
- They have a low capacity to generate force.
- Because of the way they generate their ATP, they need to have a good supply of capillaries bringing them oxygenated blood.
- They are also very good at extracting the oxygen from the blood, as they have a large amount of an oxygen-binding protein called myoglobin. This is similar to haemoglobin and gives type I fibres a colour similar to red blood cells.
- Aerobic generation of ATP can only take place inside mitochondria. Type I fibres have many of these.
- As fat can only be metabolised to produce ATP in the presence of oxygen and inside mitochondria, type I fibres are good fat burners.
- Producing ATP aerobically generates only water, heat and carbon dioxide as end products. These substances are easily dealt with by the muscle cell and are not inhibitors of metabolic processes. Due to this and their relatively slow rate of contraction, type I fibres are resistant to fatigue.
- Type I muscle fibres have a low firing threshold ie, they do not need a large stimulus in order to contract.
- Low to moderate intensity endurance-type activities, such as walking, recruit type I muscle fibres.

**Fast twitch fibres**

Fast twitch fibres fall into two groups:
**Type IIa** can generate their ATP using a mixture of aerobic and anaerobic metabolism. They are therefore called fast oxidative glycolytic (FOG) fibres.
**Type llb** fibres generate ATP anaerobically (without oxygen). These are called fast glycolytic (FG) fibres.

**Type IIa (FOG)**

These fibres produce ATP through a mixture of aerobic and anaerobic glycolysis. They are often referred to as the intermediate fibre. The energy system used to produce ATP can be influenced by the type of training, Endurance-type activities will improve aerobic glycolysis and high intensity; short duration training will improve anaerobic glycolysis. These fibres will never become true type llb or type I fibres, but, when trained appropriately, will adapt to get as close as possible.

**Type llb (FG)**

These fibres are recruited predominately during high intensity, short duration activities. These types of activity require maximum output and force generation as quickly as possible.

These fibres do not require oxygen to synthesise ATP. They can use the phosphocreatine (PC) system and lactic acid system to generate energy.

Type II fibres have the following characteristics:

- On stimulation, they reach their maximum contraction very quickly - in about 5ms -generating considerable power (which is a combination of strength and speed).
- The pathway by which they generate ATP is much quicker than for slow twitch fibres and is not reliant on an oxygen supply. It can, therefore, occur even at near-maximal heart rates, allowing high work rates and levels of performance.
- Type II fibres are thicker and contain more actin and myosin, thus increasing tension. They do not have many mitochondria, myogloglobin, or a good blood supply.
- The glycolytic pathway by which type II fibres generate ATP can only use glucose as its energy source. It produces lactic acid as its by-product. A large build-up of this acid prevents further production of ATP inside type II fibres. Therefore, they do fatigue easily at high work rates. However, if intensity eases off a little, the lactic acid diffuses out of the muscle and ATP production resumes.
- The ability to generate ATP depends on the availability of glucose (stored inside muscle cells).
- Type II muscle fibres have a high firing threshold ie, they need a large stimulus to contract.
- High intensity, short duration activities such as sprinting will recruit type II muscle fibres. They are recruited to move resistances at high speed.

| | Type I (SO) | Type II (a FOG) (b FG) |
|---|---|---|
| Speed of contraction | Slow | Fast |
| Force production (tensile strength) | Low | High |
| Capillary density | High | Low |
| Myoglobin | High | Low |
| Mitochondria levels | High | Low |
| Oxygen uptake | High | Low |
| Energy fuels | Glucose and fat | Glucose, glycogen and phosphocreatine |
| Fatigue rate | Slow | Fast |
| Colour | Red | White |
| Activity intensity | Low-moderate | High-maximal |
| Firing threshold | Low | High |

**Recruitment patterns**

Recruitment patterns of motor units are dependent on the following factors:

- Exercise intensity - low intensity activities recruit type I motor units. High intensity, explosive activities will recruit type II motor units. Some activities require varying intensities. In these cases different motor units will be recruited at different times eg, during a javelin throw, type I and type Ila fibres will be recruited during the run up, and type llb recruited for the explosive release of the javelin.
- Fitness level - a less fit individual will recruit a mixture of type I and type II muscle fibres even at lower intensities due to the inefficiency of systems to generate ATP aerobically. As a result, these individuals will fatigue quicker at lower work rates. As training continues and becomes more long term, adaptations will take place to improve the efficiency of ATP production aerobically and performance will improve.
- Skill level and coordination - with regular practice of an activity the optimal firing sequences of motor units will improve.
- Movement patterns - some activities will require a combination of muscle fibre types to be recruited at different times in the activity.

When a muscle needs to contract to lift an object or overcome a force, motor unit recruitment is not random. Small motor units, a small number of fibres per unit (therefore type I muscle fibres) are preferentially recruited, followed by type Ila and then, with increasing loads, the big ones - type llb.

Although these type llb cells can produce considerable force, they cannot maintain it for very long without experiencing fatigue due to lactic acid build-up. At very high workloads, exhaustion and damage to the myosin cross-bridges can occur.

This means that when maximal recruitment of motor units takes place, the muscle reaches the limits of its contractile power. This is the stimulus for exercise adaptation to take place. During rest the muscle compensates by making more myosin and actin filaments to add to the muscle. Insufficient rest will mean inadequate recovery and adaptation.

**Effect of muscle length on force production**

When the muscle is stretched, there is not much overlap between the myosin cross-bridges and the actin filaments. Therefore, force production is low and the perceived effort is high.

As the muscle shortens and more of the cross-bridges can make contact, the effort becomes easier as the force generated to lift the same weight is greater.

Near the very end of a lift, when the muscle is at its shortest and near its maximum contraction length, only a small amount of force can be generated and the effort needed to complete the lift therefore seems enormous. This is why the temptation to 'cheat' and perform repetitions without completing the moves is so great.

**Distribution of fibre types**

Each individual possesses a mixture of the different fibre types and the proportions of each are genetically predetermined. Most individuals will have a fairly even distribution of type I and type II fibres. Individual fibre types can be improved depending on the type of training undertaken. However, the ability to compete at the highest level in sporting events is partly determined by fibre type distribution. To compete at the very highest level of endurance events an individual would need to have a higher proportion of type I fibres. Conversely, an elite level sprinter would possess a higher proportion of type II fibre types.

Within the body there is also a distribution of different fibre types depending on location. Postural muscles such as the soleus and erector spinae which need to work at low intensity for long durations tend to have a higher proportion of type I fibres. The bigger muscles which generate movement such as the quadriceps or pectorals have a higher proportion of type II fibres for quicker, more powerful movements.

**Adaptation of muscle fibres to exercise**

Resistance training can result in hypertrophy of the muscle fibres. The process of hypertrophy involves an increase in the number of myofibrils within a muscle fibre and an increase in the synthesis of the contractile proteins actin and myosin. The new myofilaments are added to the outside of the myofibril giving it an increased diameter. Aerobic training can result in hypertrophy of type I fibres due to their increased recruitment levels. The increases are small compared to the increases of type II fibres following resistance training.

**Hyperplasia**

Hyperplasia, the splitting of individual fibres (cells) to make more fibres (cells) has been an area of debate for a number of years. Although studies have found it to be possible in animal studies, there is yet to be any conclusive evidence that hyperplasia is possible in humans.

**Changes to muscles fibre types**

It is widely accepted that due to the differing neural supply, it is not possible to change a muscle fibre from a type I to type II or vice versa. There is evidence to suggest that muscle fibres can change within a subtype. For example, during periods of resistance training there is often a change of type llb fibres into Ila. The fibres develop an aerobic ability as a result of greater aerobic demands placed on them. Although the activity may be anaerobic, the multiple recovery periods have an aerobic element as the body uses oxygen to 'pay back' the oxygen debt and replenish energy stores. If detraining follows, the fibres will switch back to type llb as they are often unused in everyday life.

Although lactic acid is a metabolic inhibitor in type II cells, it can be used for ATP production by type I cells in the form of pyruvate (pyruvic acid). Lactate diffuses out of the muscle cells into the increased blood flow where it is carried by the blood to the liver. Here it undergoes a number of chemical changes from lactate to pyruvate, back to glycogen, the storage form of glucose.

Adaptations to aerobic/endurance training:

- atrophy of type llb muscle fibres due to insufficient stimulus to recruit these motor units and muscle fibres
- hypertrophy of type I muscle fibres and type lla, particularly with resistance training
- increased capillarisation to increase delivery of blood and oxygen and increase aerobic capacity
- increased levels of myoglobin to help with oxygen utilisation
- increased size and number of mitochondria to increase aerobic energy production in the muscle
- increased fat utilisation, clue to increased oxygen delivery and fat transport into the cell
- increased endurance as glycogen stores can be spared due to improved fat metabolism
- improved recruitment of type I motor units.

Adaptations to anaerobic/strength training:

- atrophy of type I muscle fibres due to inadequate capacity to be recruited and produce ATP or force quickly enough during short, intense activities
- hypertrophy of type ll muscle fibres due to increased number of the myofilaments actin and myosin in the sarcomere
- increased force production due to improved neuromuscular connections and increased number of actin and myosin filaments.
- improved recruitment of type ll motor units.

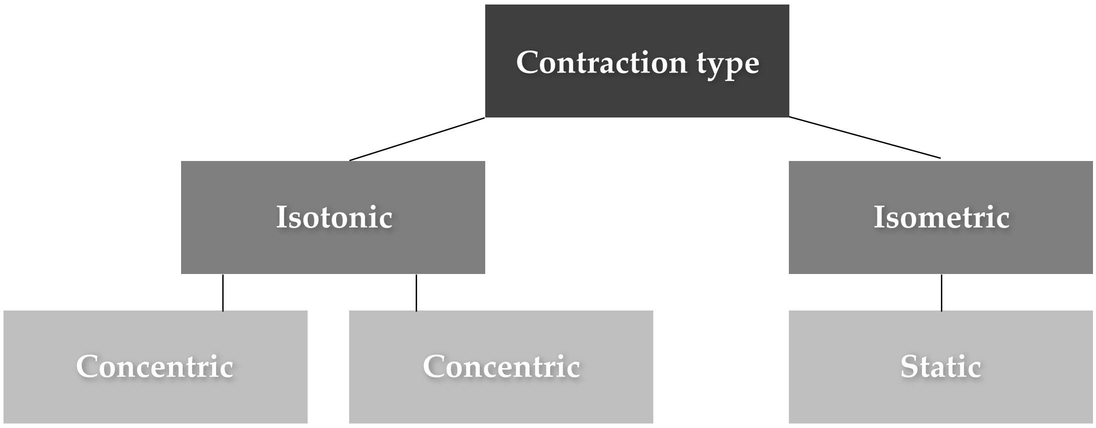
As with all training adaptations, when the training stimulus ceases, changes will revert back to their pre-trained state. This is the principle of reversibility.

**Key points of muscle structure**

- The structure of a muscle from largest component to smallest is: fascia, bundles of muscle fibres,  muscle fibre, myofibril, sarcomere, myosin filament and actin filament.
- Muscles are always in a slight state of tension.
- Muscles are linked to the nervous system by nerves.
- Slow-twitch, type I, slow oxidative fibres are best equipped for endurance work. They are slow to contract and slow to fatigue.
- Fast-twitch, type lla, fast glycolytic fibres are best equipped for strength work. They are fast to contract and fast to fatigue.
- Fast-twitch, type llb, fast glycolictic muscle fibres are best equipped for work that requires a high force quickly. They contract with high force rapidly but fatigue rapidly.

**Types of Muscular Contraction**

Muscle work is classified according to the type of contraction. There are three basic types of muscle contraction: concentric, eccentric and static.




**Concentric contractions**
When a muscle contracts, develops tension and shortens, a concentric contraction takes place. An example of this is raising the body from the floor in a press-up. This involves concentric contractions of the pectoralis major and triceps. Getting out of a chair also involves a concentric contraction of the quadriceps. In a weight-training context concentric contractions are the lifting, positive or hard work phase of the exercise.

**Eccentric contractions**
When a muscle contracts, develops tension and lengthens at the same time, an eccentric contraction takes place. An example of this is sitting down slowly in a chair, which involves eccentric contractions of the quadriceps. The quadriceps lengthen against a resistance (body weight) under control, to enable one to sit on the chair, rather than relax, which would result in falling into the chair. In a weight-training context, it is the lowering, negative or easier phase of the exercise. The eccentric phase often gets neglected, with people expending lots of effort to raise the weight and letting gravity do all the work on the lowering.

Controlled lowering of the weight in the eccentric phase can bring good improvements in muscular fitness. However, with improvement comes an increase in the likeliness of muscular soreness. Delayed onset muscle soreness (DOMS) is pain in the muscles following a workout that has been too challenging. This often occurs 12-72 hours after the workout.

Examples of eccentric contractions using the above exercises include:

- Biceps curl - eccentric contractions of the biceps occur as the weight is lowered towards the ground under control.
- Sit up - eccentric contractions of the rectus abdominis occur as the trunk is lowered towards the ground.
- Lying sideways leg lift - eccentric contractions of the hip abductors occur as the leg is lowered.

**Isotonic contractions**
Together, concentric and eccentric contractions are also often referred to as isotonic contractions. Isotonic means movement that is occurring as a result of the contraction, with one bone getting closer or further away from another bone depending upon the contraction.

**Isometric contractions**
When a muscle contracts and develops tension, and the muscle length remains the same (and therefore no movement occurs at the joint), a static, or isometric, contraction is taking place. An example of this is during a press-up. If the body is raised to the halfway point and the position is then held, only static contractions are taking place in the pectorals and triceps. If an arm is raised and held out, a static contraction of the deltoid will be taking place.

**The influence of gravity on muscle contraction**
Gravity influences the muscle contraction. An example of this is in a curl up. In this exercise, a person lies on the floor with their legs bent and curls up by contracting the abdominal muscles to flex the spine. Here the force of gravity is acting on the upper body, trying to pull it back down to the floor. The movement is therefore taking place against gravity. A concentric contraction occurs as the trunk is raised, and an eccentric contraction occurs as the trunk is lowered.

However, if a person stands upright and performs a similar movement (flexion of the spine), the movement will be taking place with gravity and thus the exercise would involve other muscle groups (erector spinae working eccentrically on the lowering and concentrically on the raising) and would be totally ineffective for the abdominals. By changing the body position in relation to gravity, both the emphasis of the exercise and the muscle groups involved have been completely changed.

**Levers and biomechanics**
This factor can also affect how hard a muscle needs to work to achieve a contraction. The longer the lever, the more muscular effort is required to bring about the contraction. An example of this is when performing an abdominal curl. If the arms are raised above the head, the lever (from the pivot point - hips - to the tips of the fingers) is lengthened. If the hands were to the side of the head, the pivot is shorter.

## Key points of muscle structure

- A muscle can only pull across the joint(s) it crosses and in its line of fibre.
- Muscles work in pairs.
- Muscles attach to bone via a tendon, onto the aponuerosis of other muscles or directly onto the bone.
- Prime mover (or agonist) is the main muscle responsible for the movement.
- Antagonist is the muscle which produces the opposite movement to the prime mover.
- Fixator muscles help fix the body in the correct position to allow other movements to take place.
- Synergist muscles help the prime mover to achieve its goal.
- There are specific changes to muscles for special populations.

**Special populations and the muscular system**

**Children**
Genetically, children inherit from their parents the proportion of each type of muscle fibre in their body. Muscle growth does not keep up with bone growth, which can sometimes make children appear clumsy and awkward. Muscle growth varies in children depending on age, gender and body type.

**Pregnancy**
Pregnancy has an effect on the muscular system in relation to the laxity of each muscle. The hormone relaxin is responsible for increasing the pliability of muscle connective tissue, especially in the later stages of pregnancy. Instructors may need to be aware that this may have an effect on balance and co-ordination, as well as increasing flexibility. Therefore, it is beneficial that short maintenance stretches are used during this time, as opposed to development stretches, to avoid damaging connective tissue.

**Ageing**
From the age of 40, the muscular system starts its decline. This degeneration results in a reduction in the number of muscle fibres and muscle fibre size, replacement of muscle tissue with non-contractile fibrous tissue and a reduction of motor units and neurons. The resulting loss of muscle mass leads to a reduction in power, strength and endurance. This in turn leads to a progressive reduction in the level of support afforded to the skeleton and gradual changes in posture. The accompanying weaknesses will have an impact on motor skills, especially co-ordination and balance, thereby increasing the chance of a fall.

**Disabilities**
There are a range of medical conditions and disabilities that have an impact on the function of the muscular system

## Key points of muscle contraction

- There are three types of muscle contraction: concentric, eccentric and static.
- A concentric contraction is when a muscle shortens against a resistance.
- An eccentric contraction is when the muscle lengthens against a resistance.
- Together, concentric and eccentric contractions are referred to as isotonic contractions.
- An isometric or static contraction is when a muscle is actively engaged in holding a static position.
- Gravity and lever length influence muscle contraction.
- Breathing out during the lifting phase and in during the lowering phase of an exercise is recommended to avoid the Valsalva effect.

# Posture and Core Stability

This section describes the importance of posture. It describes the terms posture and core stability and how these two components affect performance. The supporting structures of core stability are explained along with the function of intra—abdominal pressure.

**Objectives**

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

- describe the structure and function of the stabilising ligaments and muscle of the spine
- describe local muscle changes that can take place due to insufficient stabilisation
- explain the potential effects of abdominal adiposity and poor posture on movement efficiency
- explain the potential problems that can occur as a result of postural deviations
- explain the impact of core-stabilisation exercise and the potential for injury/aggravation of problems
- explain the benefits, risks and applications of the following types of stretching:
    - static (passive and active)
    - dynamic
    - proprioceptive neuromuscular facilitation (PNF).

**Core Stability**

The term core stability refers to the ability to prevent unwanted movement of the body's centre. Core stability is so important because the axial skeleton provides a base for movement of the appendicular skeleton. The axial skeleton provides the foundations for movement. The more stable these foundations are, the greater the control provided for movements of the appendicular skeleton.

As an individual moves their arms and legs, forces are applied to the core. These forces either cause additional unwanted (de-stabilising) movement, or if core stability is working effectively, no additional unwanted movement.

Core stability is provided by three different systems:

- passive system - the spinal column itself and spinal ligaments
- active system - muscular activity
- neural control - feedback from the proprioceptors in the above systems.

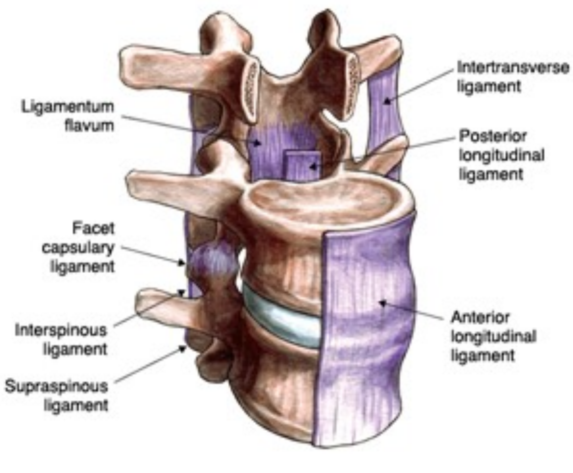
**Passive system**
The passive system uses the structure and arrangement of the vertebrae and discs along with the spinal ligaments to provide stability. The vertebral column is structured so that when in its optimal position with all the normal curvatures it can provide support and absorb impact.

The ligaments involved in assisting with spinal stability are the posterior longitudinal ligament, the anterior longitudinal ligament and a collection of lots of smaller lateral ligaments.

The posterior longitudinal ligament extends along the length of the spine on the posterior surfaces of the  vertebral bodies. It helps to prevent excessive forward flexion. It is relatively weak, so is prone to injury when forward flexion occurs with momentum.

The anterior longitudinal ligament extends along the length of the spine on the anterior surfaces of the vertebral bodies and discs. It is a broad, flat ligament that helps to prevent hyperextension of the spine.

Located laterally between each individual vertebra are many other smaller ligaments that connect one vertebra to the adjacent vertebrae. These ligaments are also prone to injury so caution should be used during lateral flexion and rotation of the spine.



**Thoracolumbar fascia (TLF)**

Another key factor in the passive system is the thoracolumbar fascia (TLF). The TLF is a sheet of ligamentous connective tissue covering the lumbar spine and SI joint. It is primarily made of collagen so has no contractile properties. Various muscles connect to the TLF, including transverse abdominis, internal obliques, external obliques, trapezius, latissimus dorsi and gluteus maximus. Because of its attachment to the TLF, the gluteus maximus is also a spinal stabiliser. It is not uncommon to experience back pain as a result of weakened gluteus maximus muscles, which is compensated for by an overactive erector spinae.

When the muscles attaching to the TLF create a balanced pull it provides another mechanism of stability  for the lumbar spine and Sl joint providing an additional posterior sheet of support. This is particularly useful in controlling forward flexion.

The TLF is also important in the transfer of loads throughout the lumbar and thoracic regions of the spine. The TLF crosses the lumbar spine. This means loads can be effectively transferred from the leg on one side of the body to the latissiumus dorsi muscles and arm on the opposite side of the body. The attachment of the gluteus maximus and latissimus dorsi into the TLF means that forces during walking and running can be transferred from the gluteus maximus on one side of the body to the latissimus dorsi on the opposite side of the body through the tension generated in the TLF during the contraction of these muscles. This further stabilises the lumbar spine and SI joint.

If the muscles pulling on the TLF are imbalanced in any way the support can be weakened and dynamic posture compromised, resulting in a subsequent increase in injury risk.

**Other mechanisms that support the vertebral column**

**Intra-abdominal pressure (IAP)**
The erector spinae muscle group provides the majority of support to the spine during flexion. However, the abdominal muscles may also help to support the spine in flexion as well. They do this by forming an abdominal 'balloon'. Visualise the trunk to be a roughly cylindrical shape. The rectus abdominis, obliques and transverse abdominis (TVA) form the sides of the cylinder. The pelvic floor muscles form the bottom of the cylinder, and the diaphragm the top of the cylinder. When the intra-abdominal pressure inside this cylinder is increased, by contracting the aforementioned muscles and momentarily holding the breath, it forms a 'balloon' that adds a small amount of support to the spine and prevents it from flexing forwards.

Most experts agree that increased intra-abdominal pressure helps to support the spine. However, there is considerable debate between those experts about exactly how the mechanism works, and what degree of support is generated in this way. For example, the amount of intra-abdominal pressure needed to give  significant support would, some claim, be enough to squeeze and occlude the inferior vena cava returning blood to the heart. This would obviously have serious consequences.

**Abdominal bracing**
Some researchers have questioned the common advice to 'pull in' the abdominal wall, or 'engage the TVA' for the purposes of increasing spine stability. Pulling in the abdominal wall, along with breath holding would increase intra-abdominal pressure as discussed, with a probable increase in spine stability. However, pulling in also makes the line-of-action (leverage) of the rectus abdominis

and obliques less efficient, effectively decreasing the support they can offer to the spine to resist extension, lateral flexion, and rotation.

For heavy lifting, abdominal ‘bracing’ has been suggested as an alternative to ‘pulling in’ (McGill, 2002). Bracing the abdominals means contracting all of the abdominal muscles to make the abdominal wall firm (as if about to be punched in the stomach), but not pulling them in. In this way, intra-abdominal pressure can be increased by holding the breath, but the leverage of the surrounding muscles is not reduced.

**The active system**

The active system is made up of the muscles of core. These muscles can be divided into local (deep muscles) and global muscles (superficial muscles).

Local (deep) muscles include:

- transverse abdominis (providing anterior support)
- multifidus (providing posterior support)
- quadratrus lumborum - internal obliques (providing lateral support)
- pelvic floor muscles (providing inferior support)
- diaphragm (providing superior support)

Local muscles are located close to the spine and are recruited prior to gross movement to prevent. unwanted movement. They play a vital role in maintaining a neutral spine position. This is the position of the spine in which impact and forces can be absorbed and transferred most effectively. It is important for this position to be maintained as successfully as possible to reduce the stress placed on the ligaments Of the spine and reduce injury risk (for location and attachment sites for the first four muscles listed above, see the previous section 'the musculoskeletal system’).

When these muscles work in balance with each other they create a cylinder of support around the spine, otherwise known as hoop tension. This creates an increase in pressure through the centre of the cylinder, known as intra-abdominal pressure (IAP), and provides increased stability for the spine.

Breathing plays an important role in creating IAP. When humans breathe in; the diaphragm contracts and flattens. This increases IAP and therefore spinal support. Elite weight lifters and power lifters often inhale maximally and hold the breath for a lift in order to increase intra-abdominal pressure and help protect the spine from injury. However, breath holding during activity is not advised due to the Valsalva effect (see the ’heart and circulatory system’ for further information on the Valsalva effect).

**Pelvic floor muscles**

The pelvic floor is a double-layered (deep and part-superficial layer) broad sling of muscle from the pubic bone at the front to the base of the spine at the back of the pelvis, comprising the coccygeus and the levator ani. It consists of both fast and slow- twitch muscle tissue - a point that should be taken into consideration for effectively exercising these muscles. The combination of these two types of fibres enable it to maintain tone and endurance and also respond immediately to a sudden rise in abdominal pressure eg, coughing, laughing, exercising.

The pelvic floor provides:

- stability of the pelvic girdle
- support for the organs of the pelvis and abdominal contents, as well as for the foetus when pregnant
- continence control of urine and faeces
- reflex activity to counteract changes in abdominal pressure (ie, coughing, sneezing, nose blowing, vomiting and forced expiration)

During pregnancy, the pelvic floor muscles have the ability to stretch considerably to allow for childbirth. However, this can leave them weakened.

Pelvic floor muscles can become weak and sag not only from childbirth but through lack of exercise, the menopause or simply due to the ageing process. However, in the same way as one would train any other muscle group, it is also possible to train these muscles to improve and maintain their ability to effectively support the pelvis.

Global (superficial) muscles include:

- rectus abdominis
- external obliques
- erector spinae (iliocostalis, longissimus, spinalis)

These muscles are superficial and either prevent or produce a specific joint action. During exercise these muscles usually challenge the strength and stability of local muscles. (See the previous section 'the musculoskeletal system’ for location, actions and attachments sites).

**Muscular imbalance**

It is important to include exercises in a programme for core stability that engage both local and global muscles. If global muscles are overworked to the detriment of the smaller local stabilising muscles, the movement produced by the larger muscles will lack stability and technique. For example, if a swimmer does not have sufficient strength in the stabilising muscles of the spine, the movement of the limbs during their stroke will be poor and inefficient and have a negative impact on their performance. A strong and stable core allows effective transfer of effort and load to the limbs for maximum efficiency and output.

If the larger movement-producing muscles of the spine are overworked and the local stabilising muscles are neglected, postural imbalances can result, along with back pain due to excessive loads being placed through the vertebral column. This is of particular concern in the lumbar spine as there is no skeletal support in this region and it relies on the IAP created by the balance of muscular contraction on structures such as the TLF. If this balance is compromised, injury risk during activity is much higher.

This doesn't just apply to the trunk muscles of core stability. This principle can also be seen in other areas of the body such as the shoulder. The larger muscles of movement in the shoulder include the pectoralis major, the latissimus dorsi and the deltoids. If these dominant muscles are overworked to the expense of the stabilising muscles of the rotator cuff (supraspinatus, infraspinatus, teres minor and subscapularis), the movement produced will be poor and lack stability, eventually leading to injury and poor alignment. Over time, if this imbalance is not addressed, the smaller muscles will atrophy (get smaller) and become looser and weaker.

**Abdominal adiposity and poor posture**
Abdominal adiposity affects centre of gravity and has implications on posture. It has implications on exercise performance and can affect balance, stability and alignment; all of which need to be considered when working with clients that carry more weight in the abdominal area.

**Neural control**
Proprioceptors play an important role in the sequence that muscles contract, in order to prevent unwanted/wanted contraction of muscles. The proprioceptors involved are the muscle spindles in the belly of the muscles and the Golgi tendon organs located in the tendon. Feedback from these structures allows the body to contract or relax muscles in order to adjust posture and core stability and prevent injury.

**Correct spinal alignment**
Good posture can be defined as 'the arrangement of body parts in a state of balance'. An important part of this state of balance is the concept of a 'neutral' spine position. A neutral spine is one that maintains each of the four curves, rather than extending, flexing or twisting excessively. For example, a neutral lumbar spine is halfway between a flat lower back (pelvis titled fully backwards) and an arched lower back (pelvis tilted fully forwards).

The ability to maintain a neutral spine is important for:

- prevention of joint and ligament damage within the vertebral column
- performing weight-bearing exercises with biomechanical efficiency
- the transmission of stressors through the pelvis, caused by impact.

**Back pain**
There are many potential causes of back pain as a result of postural deviations:

Muscle strain - back pain can be caused simply by overstraining and pulling a muscle. This usually aches for several days but gradually resolves itself. The aching may be noticed particularly when picking up objects from the floor, or in transitions from lying to seated and standing.

Ligament sprain - a partial tear, or 'sprain', of the spinal ligaments can result from twisting and flexing movements beyond the normal range of movement. Sprains will also resolve themselves, but they do take longer than muscle-related problems.

Bulging or prolapsed discs - performing a variety of safe movements helps to keep discs 'supple' and healthy, but continually performing uncontrolled movements that repeatedly stress the discs in one direction can lead to injury.

Excessive flexion of the spine can cause the vertebrae to pinch the anterior part of the disc, which in turn makes the posterior part of the disc bulge. Excessive extension can cause the vertebrae to pinch the posterior part of the disc, which in turn makes the anterior part of the disc bulge.

If flexion and extension is combined with a rotation movement, then additional torsional stress is also placed on the disc. In time, a disc may start to bulge permanently, or even rupture (prolapse) and press on a nerve root. This is a common cause of pain in both the lower back and neck regions.

Osteoarthritis - as people age, they may develop osteoarthritis in the facet joints between adjacent vertebrae due to cumulative wear and tear. The resulting inflammation can be a source of pain. Osteoarthritis is not reversible, but the effects can usually be managed with a combination of appropriate exercise and medication.

**Exercises to improve core stability**

Various exercises can be offered to improve an individual's core stability. It is important to assess each individual's posture before prescribing exercise, to ensure that any deviation from the ideal is addressed. The goal is to improve posture first, then create stability in that posture. Postural realignment training comes before core stability training.

While specific exercises stated below are aimed specifically at improving core stability, any exercise should be taught with attention to posture. This includes static exercises (when the individual remains in one place) while standing, seated or lying, and dynamic exercises.

Often it is the failure of the core muscles that causes the failure to complete an exercise involving movement of the arms or legs; if the spine cannot be stabilised, there is no base around which the arms or legs can move.

The muscles involved in core stability need to be able to do their jobs for extended periods of time. Core stability training should reflect this, with exercises practised not only with increasing resistance, but also for increasing duration.

All these exercises are influenced by breathing because the position of the diaphragm has an effect on the top of the cylinder that creates intra-abdominal pressure.

Commonly used exercises include:

- prone lying abdominals/plank
- supine lying abdominals
- four-point balances.

**Using equipment**
Some people will find the exercises more enjoyable using equipment. The above exercises, plus many others, can be performed using a stability ball or stability disc. This works to create an unstable surface, encouraging stabilising muscles into action. This can improve body awareness of the stabilising muscles far more quickly with far less teaching. It is important to remember training

specificity, to ensure that if the individual wants to stabilise themselves on a stable surface (such as a floor) then they will also need to practise some exercises on a stable surface.

**Benefits of improved core stability**

By improving the muscles of the core the following benefits can result:

- decreased risk of injury to the spine, shoulder girdle and associated joints
- improved application of force from the limbs in an unsupported environment as a result of having a more stable base to work from
- improved appearance (flatter lower abdomen)
- improved balance and motor skills (reduced body sway when standing on an unstable base)
- reduction in lower back pain
- improved lung capacity for those with kyphosis, due to increase in size of thoracic cavity
- decreased risk of falls due to corrections in the centre of gravity.

**Stretching and its role in core stability**

Along with improving the tone and endurance of core stabilisers it is equally important to ensure range of movement and functional flexibility are maintained, without these it is impossible to have muscular balance, as discussed earlier in this section.

There are different types of stretching, all of which can help to maintain and in some cases improving flexibility.

**Static stretching**
Static stretches are performed by the person moving slowly into position until a stretch is felt in the target muscle. The stretch is then held for several seconds.

Flexibility improvements apparently result from the desensitisation of the stretch reflex and lengthening of connective tissue.

Static stretches are suitable for most participants because they give good results with a low risk of injury.

**Dynamic stretching**
Dynamic stretches are performed with controlled movements. They prepare muscles well for exercise by combining range of movement work and muscle warming.

If not controlled, dynamic stretches can become ’ballistic' - meaning that they are done with fast bouncing movements. This may cause short and long-term damage to muscle fibres and connective tissue.

Dynamic stretches are particularly appropriate for warm up in sporting or skill-based activities, such as football or exercise to music.

**Proprioceptive neuromuscular facilitation (PNF)**
Proprioceptive neuromuscular facilitation, or 'PNF' stretching, involves a controlled contraction of the muscle immediately prior to it being stretched. The mechanisms involved in this type of stretching are covered in more detail in the nervous system chapter.

PNF stretching has a higher risk of injury than dynamic or static stretching, due to the high degree of tension generated in the muscle.

PNF is an alternative approach to static stretching, but as it involves partner work it is more suitable for a client working with a skilled fitness professional.

# The Energy Systems

**Introduction**

The term 'energy' means different things to different people. For example, a physicist might say that it's 'the capacity for doing work' and start talking about mechanical, chemical and electrical energy.

The following section aims to provide the learner with an understanding of how chemical (food) energy is converted into usable fuel and how energy for the body is used within the muscles. The way in which energy is produced varies depending on the activity being performed. This section should help in assessing which energy systems are used when performing physical activities or sports.

**Objectives**

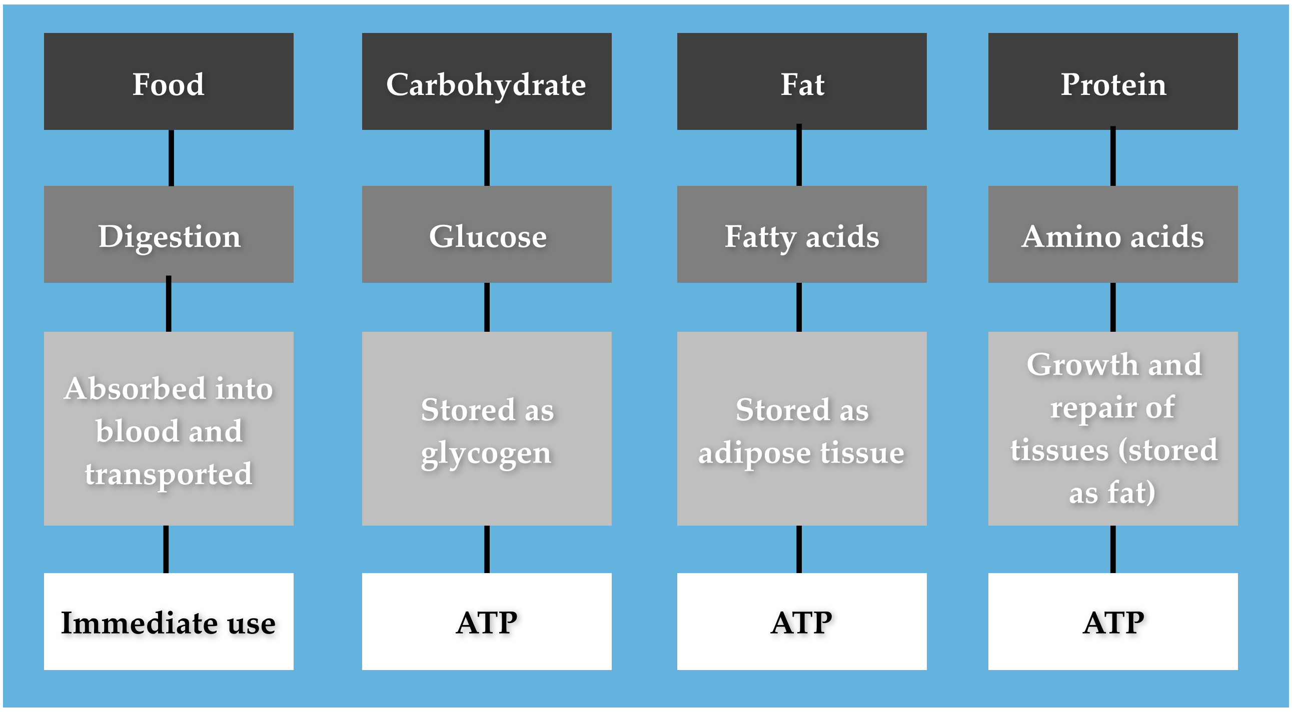
By the end of this section, the learner should be able to:

- describe how carbohydrates, fats and proteins are used in the production of energy / adenosine triphosphate
- explain the use of the three energy systems during aerobic and anaerobic exercise.

**Energy**
In order for the body to function, it needs energy - even at rest. When someone begins exercising, the body must start producing energy at a faster rate than it does at rest. As the muscles contract more frequently, the heart beats faster, pumping blood around the body. All these processes require energy.

**Energy sources**
Energy comes from the food we eat, including:

- Carbohydrate - this is stored in our muscles and liver cells in the form of glycogen. Glycogen is broken down into glucose, the fuel that can be used by all tissues in the body. Carbohydrate should provide around 50 to 60 % of total energy.
- Fat - this is stored beneath the skin (adipose tissue), where it serves not only as a fuel store but also as insulation to prevent heat loss. Fat is composed of triglyceride molecules that are broken down in to fatty acids to release energy. Fats should provide about 30% of total energy.
- Protein - this is used as a building material for the growth and repair of tissues of the body. As such, it is not stored in the body in the same way as fat and carbohydrate, unless there is excess, when leftover protein will be converted to fat and stored. Protein can be broken down to amino acids to provide energy. This, however, only occurs during prolonged endurance events (eg, long distance swimming or cycling). Protein should provide around 10 to 15% of total energy.



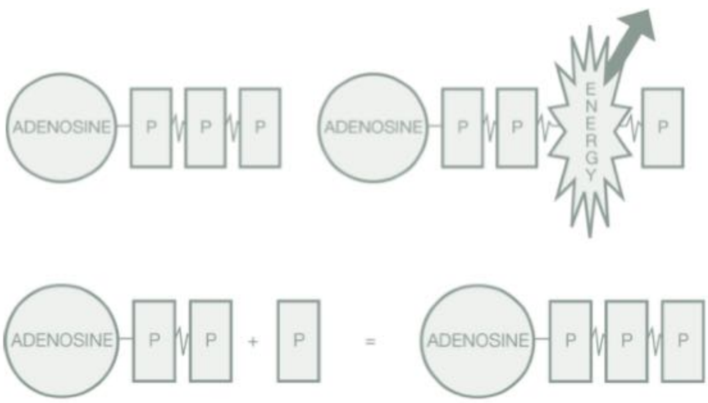

**What is energy?**

**The ATP/ADP cycle**

Energy is released in the body by the breakdown of carbohydrates, fats and proteins to produce adenosine triphosphate, or ATP. ATP is often referred to as the body's ‘energy currency’, because it is the only currency the body accepts to provide energy. All forms of biological work (digestion, production of hormones, transmission of nerve impulses, manufacture and repair of tissues, etc) within the body require energy in the form of ATP.

ATP consists of a substance called adenosine and three phosphate groups. Special high-energy bonds exist between the phosphate groups. Energy is released by breaking one of the phosphate bonds. In a muscle cell, the breakdown of ATP results in mechanical work (muscle contraction) and heat. This explains why one feels warmer during exercise.

When ATP loses one of its phosphate bonds, energy-is produced, which is then converted to ADP (adenosine diphosphate), as shown in the diagram below. Once this has occurred, ADP is re-synthesised back into ATP by a process called 'coupled reactions’, which is a bit like a shuttle system. This process is called the ATP cycle, and is important for the constant generation of energy within the body. If this process stops, so does life as we know it!



**Key points of fuels for exercise**

- Carbohydrate is broken down to glucose in the body to provide energy.
- Fat is broken down to fatty acids in the body to provide energy.
- Protein is broken down to amino acids in the body that can provide energy in extreme circumstances.
- The breakdown of all three fuels in the body produces ATP.
- Energy is produced when ATP loses one of its phosphate bonds. When this occurs, ATP becomes ADP.
- ADP is resynthesised to ATP by a process called 'coupled reactions'.

**Energy Systems**

When someone begins exercising, the energy demand increases suddenly and the body's stored supply of ATP is used within a couple of seconds, so more fuel must be quickly broken down to produce further ATP.

ATP can be resynthesised in three different ways. These are referred to as the 'energy systems', including:

- phosphocreatine (PC) system
- lactic acid system
- aerobic system.

The PC and lactic acid systems are termed 'anaerobic' because ATP is produced very quickly without the presence of oxygen. The third energy system (aerobic) produces ATP more slowly in the presence of oxygen.

**1 . Phosphocreatine energy system**

The phosphocreatine (PC) system utilises a fuel called creatine phosphate to make ATP. Creatine phosphate is a high-energy compound that is stored in limited amounts within the muscle. When the high-energy phosphate bond in creatine phosphate is broken down, the released energy is immediately used to resynthesise ATP. This means that as rapidly as ATP is broken down for muscular contraction, it is reformed by the bonding of ADP and freely available phosphate (P) within the muscle cell.

This system is used for instantaneous bursts of activity lasting for just a few seconds. It is an energy system that is predominantly used in explosive sports, such as the long jump, shot put or 100m sprint. In a similar way, this system is used for everyday activities, such as when dashing for the bus or train. The phosphocreatine system can be thought of as a back-up system to ATP, as it helps to regenerate ATP from ADP immediately.

From an exercise point of view, the major limitation of the phosphocreatine system is that the stores of creatine phosphate within the muscles are very limited (only lasting seconds, when working at maximum intensity). After this, creatine phosphate must itself be regenerated (taking two minutes or longer). This means that other fuels, such as glycogen and fat, must then supply energy for the regeneration of ATP. When this happens, other energy systems-take over.

Creatine phosphate is stored in the sarcoplasm of muscle cells. There are very limited stores of CP in the muscle cells. The energy released from the breakdown of CP is used in the endothermic reaction to reattach a free phosphate to the adenosine diphosphate to reform adenosine triphosphate. Since the supplies of CP are so limited, this re-synthesis will only last up to 10 seconds before the supplies of CP are used up.

Fast twitch muscle fibres (FG) will use the phosphocreatine system for energy production. Their low aerobic ability means that they need to use an energy system that can provide energy without the use of oxygen (anaerobically). Their suitability to short bursts of intense activity also means that the best energy system for them to utilise is the phosphocreatine system.

**2. Lactic acid energy system**

The lactic acid system utilises glycogen in the absence of oxygen to make ATP. Glycogen is stored in limited amounts within the muscle and is broken down to pyruvate and then to ATP. This process is called ‘anaerobic glycolysis‘ and a by-product of this is lactic acid. Lactic acid formation can pose a significant problem in performance conditions because high levels can lead to muscle fatigue, usually referred to as ‘feeling the burn‘.

The lactic acid system provides energy for very quick bursts of high-intensity activity, lasting on average less than a minute (at maximum effort). This energy system is used when weight-training and performing a set of 8-12 repetitions to failure, or running 400 metres.

There are two major limitations of the lactic acid system. First, like creatine phosphate, the store of glycogen in the muscles is limited. Second, with continuous high-intensity exercise, the rapid conversion of glycogen to ATP without oxygen produces a build-up of lactic acid in the muscles. If the rate of lactic acid production exceeds its rate of removal, muscles become fatigued and muscle contraction is impeded.

To avoid fatigue, exercise intensity must be reduced so that the lactic acid can be carried away from the muscles by the bloodstream to the liver, for conversion back into glucose or to be used by other cells receiving a sufficient supply of oxygen. This slowing down also means more oxygen is available to the muscles. This is termed repaying the ‘oxygen debt‘.

Anaerobic glycolysis means the breakdown of glycogen in the absence of oxygen. The breakdown of glycogen into pyruvic acid results in the production of two molecules of ATP.

This is a simplified representation of glycolysis where a total of 10 complex chemical reactions are required to convert glycogen into pyruvic acid. Bearing in mind the principles of human efficiency, the lactic acid system requires considerable effort for a relatively low yield of ATP.

In the absence of oxygen, the by-product of the lactic acid system - pyruvic acid - combines with hydrogen ions to form lactic acid.  The presence of lactic acid in the blood can be felt as a cramping/burning sensation in the muscles, which impedes performance and cannot be tolerated for very long. The lactic acid system is sustainable for about 2-3 minutes.

The point at which lactic acid begins to accumulate faster than it can be removed is called onset of blood lactate accumulation (OBLA) or anaerobic threshold. At this point blood lactate concentration levels are approximately 4mmol, although this can vary between individuals. Onset of blood lactate accumulation is directly related to exercise intensity.

**3. Aerobic system**

The aerobic production of ATP takes place in the presence of oxygen using a mixture of glucose and fatty acids as the fuels. Amino acids can also be used when carbohydrate stores are low, such as during prolonged events.

This process occurs within specialised structures in the muscle cell called mitochondria (often referred to as the 'powerhouse' of the cell) that contain special enzymes needed by the cell to use oxygen.

Note: Enzymes are proteins that accelerate chemical reactions within a cell.

As previously explained, glycogen is stored in limited amounts within the muscle and is broken down to pyruvate prior to ATP. The aerobic system allows this process to occur in the presence of oxygen; therefore instead of forming lactic acid, other by-products such as carbon dioxide and water are formed. This is a cyclical process and is more efficient at producing ATP. This is called aerobic glycolysis.

The aerobic energy system is used for sustained activity lasting more than 90 seconds (eg, swimming, cycling, walking, the 10,000 metres, exercise to music and circuit weight-training).

A key adaptation to regular aerobic training is that the body becomes more efficient in mobilising, transporting and oxidising fatty acids. This is because the body develops a greater number of mitochondria and fat-oxidising enzymes. Consequently, the body becomes more efficient at burning fat. This is one reason why aerobic exercise can help to control or lose body fat.

For endurance activities, this improved utilisation of fat is important because glycogen is in much shorter supply than fat. By using more fatty acids, glycogen stores can last longer.

However, the main limitation of the aerobic system is that it is slow to engage. This is because of the complex series of chemical reactions involved and the fact that it takes a couple of minutes for the heart to increase the delivery of oxygen-rich blood to the exercising muscles. During anaerobic work, creatine phosphate or glycogen must be converted very quickly into energy to meet the exercising body's demands. The cost of this fast-delivery service is that this service is limited. The cost of aerobic energy production is that it is a very slow-delivery service; however, it is still about 20 times more efficient in terms of energy production.

The body cannot continue working in the lactic acid system once OBLA occurs and so has to lower the intensity of the activity to continue. Now the body must again seek out an alternative method of producing ATP. It does this by the third energy system which is only possible in the presence of oxygen. This is the aerobic system.

Aerobic system summary

- The aerobic system is the only one of three energy systems that is completely sustainable over many hours at a low-to-moderate intensity.
- It can produce large amounts of ATP, but must have oxygen present to do this.
- It can utilise fats and carbohydrates for fuel. Proteins can also be used, but usually only in the absence of sufficient carbohydrate.
- The main by-product of the aerobic system is carbon dioxide.

| Energy System | Fuel used | Rate of ATP production | Capacity of energy system | Main use |
|---|---|---|---|---|
| Phosphocreatine | Creatine phosphate (stored in the muscle) | Very rapid | Very limited ATP production | Very high intensity, short duration activities lasting up to 15 seconds |
| Lactic acid | Glycogen (stored in the muscle and liver) | Rapid (by-product is lactic acid that can lead to muscular fatigue) | Limited ATP production | High intensity, short duration activities lasting 30-40 seconds |
| Aerobic | Glycogen, fatty acids (stored in adipose tissue) | Slow (by-products are carbon dioxide and water) | Unlimited ATP production | Moderate to vigorous intensity, long-duration activities lasting for more than 90 seconds |

The higher the exercise intensity, the more dependent the body is on glycogen. The type of fuel used by the body depends upon the exercise duration, intensity and type.

While it is convenient to explain these energy systems in isolation, when exercising, energy will be derived  from all three systems. However, the emphasis will change according to the intensity of the activity relative to the person's fitness level.

Sports that involve short, sharp, intense bursts of activity, such as jumping, sprinting and throwing, are predominantly anaerobic. Sports that involve sustained rhythmical movements for long periods, such as cycling, swimming, rowing and skiing, are predominantly aerobic. However, most sports are a mixture of both anaerobic and aerobic. For example, netball, football, rugby, hockey, volleyball and basketball entail short bursts of high-intensity activity interspersed with longer periods of low to moderate intensity activity.

**Training the energy systems**

**Training the ATP-PC system (phosphocreatine system)**

Training this system should be done at maximum intensity, 95-100%. An example would be a 100m sprint or an explosive tennis serve. In weight lifting, maximum strength is developed by lifting heavy weights with a guide of 3-5 repetitions and 3-5 sets with 3-5 minutes recovery.

| PC system training is aimed at: | Methods of training: |
|---|---|
| • Improving strength, power and speed<br>• Increasing stores of ATP-PC<br>• Increasing the size of specific muscles | • Acceleration sprints<br>• Short sprint interval training<br>• Running up hills<br>• Running up stairs<br>• High weights/few reps |

Physiological adaptions:

- Hypertrophy of the muscles - which allows greater storage capacity of ATP and PC.
- Improved motor unit recruitment.
- Decrease in body fat - this is due to the fact that fat is burned during the recovery phase of high intensity training (very little fat is burned during short high intensity training).

Advantages and disadvantages of the ATP-PC system

| Advantages | Disadvantages |
|---|---|
| • ATP is present in the muscles<br>• It is an immediately available source of energy<br>• It is a fuel for fight or flight survival<br>• It provides an explosive Burt of power<br>• No waste products are produced | • Limited supply of ATP<br>• ATP has to be resynthesised<br>• It requires relatively long recovery/ replenishment time, 3-5 minutes to restore to 100%<br>• It is quickly exhausted, lasting up to only 10 seconds |

**Training the lactic acid system**

Training this system should be done at a moderate to high intensity, 75-85%. An example would be a 400m run or canoeing against a current.

| Lactic acid system training is aimed at: | Methods of training: |
|---|---|
| • The components of fitness: muscular endurance and strength<br>• Overloading the system causing large amounts of lactic acid to be produced<br>• Increasing lactate tolerance and thus increasing the anaerobic threshold<br>• Increasing the rate of lactate removal | • Repeated bouts of exercise at moderate to high intensity<br>• Short recovery<br>• Programmes lasting several months (focusing on the aims in the first column) |

Physiological adaptions:

- Increased muscular strength.
- Delayed onset blood lactate accumulation.
- Increase in the hydrogen ion (H+) buffering capacity. The trained athlete can tolerate higher levels of lactic acid in their blood compared to non-trained individuals.

Advantages and disadvantages of the lactic acid system

| Advantages | Disadvantages |
|---|---|
| • It supplies additional ATP in the absence of oxygen | • It produces lactic acid which impairs/inhibits performance<br>• Recovery (removal of lactic acid) can take up to 1 hour<br>• It can create a large oxygen debt (the difference between the amount of oxygen required for a given level of effort/intensity and the amount of oxygen actually available). Oxygen debt can be measured as EPOC (Excess Post-Exercise Oxygen Consumption) |

**Training the aerobic energy system**

Training should be done at low-to-moderate intensity, 60-75%. Some team games utilise the aerobic energy system; a marathon runner utilises this system and can take hours to complete a race. Elite marathon runners and triathletes are fat burning furnaces! Their aerobic threshold will be very high, allowing the body to burn a greater proportion of fat even at higher intensities, allowing them to continue the activity for longer periods of time without depleting their glycogen stores.

| Aerobic energy system training is aimed at: | Methods of training: |
|---|---|
| • The components of fitness: cardiovascular strength/endurance; muscular endurance<br>• Increasing aerobic energy stores of muscle glycogen and triglycerides and thus increasing the aerobic threshold<br>• Increasing size and density of mitochondria<br>• Increasing myoglobin | Cardiovascular endurance training such as:<br><br>• Swimming<br>• Cycling<br>• Long distance running<br><br>Limiting rest breaks |

Physiological adaptions:

- Increased cardiovascular strength and endurance.
- Increased capillarisation.
- Increased mitochondria.
- Increased glycogen and myoglobin stores.

- Increased ability to mobilise fat as a fuel, sparing glycogen which reduces lactate production.
- Increase in blood volume, stroke volume and cardiac output.
  (cardiac output = stroke volume x heart rate).
- Better utilisation of oxygen. There is an increased ability to work at a higher percentage of VO2 max.

Advantages and disadvantages of the aerobic energy system

| Advantages | Disadvantages |
|---|---|
| • It is sustainable over long periods at low-to-moderate intensities. | • It is not effective if explosive bursts of speed or strength or power are requires immediately<br>• Dependant on oxygen supply (and cardiovascular fitness levels) |

## Energy systems and special populations

### Children

Children utilise more mitochondria in their muscles and therefore are able to utilise oxygen more effectively. They have a high anaerobic threshold, so as long as they are working at an appropriate intensity, they are able to keep going. However, they naturally have limited supplies of muscle and liver glycogen, as well as smaller stores of anaerobic fuel and the capacity to use it. This limits their anaerobic capacity and they are not able to tolerate short bursts of energy or exercises/activities that require high intensity and short repetitions. However, this does improve as they get older.

### Pregnancy

There is a gradual increase in energy expenditure as pregnancy advances. Pregnant exercisers use more carbohydrates than fat during moderate exercise. Therefore, blood sugar levels can fall quickly. It should be noted that blood glucose can be reduced after strenuous exercise, especially in the later stages of pregnancy.

### Ageing

The ability of skeletal muscle to produce energy becomes less efficient with age. Although resting levels of ATP and creatine phosphate are similar in the young and old, active levels decline in older people, suggesting that they are less able to regenerate ATP. Additionally, the enzymes responsible for energy release reduce in concentration and effectiveness, thus contributing to reduced energy production.

### Disability

There are a range of medical conditions and disabilities that have an impact on the function of the energy systems specific to the individual.

### Key points for energy systems

- The phosphocreatine system is an anaerobic system that uses creatine phosphate, which is stored in the muscles in limited supplies (enough for up to 15 seconds of high—intensity work).
- The lactic acid system is an anaerobic system that utilises glycogen, which is stored in the muscles (in limited amounts) and the liver.
- Glycogen supplies within the muscles are sufficient for high—intensity exercise lasting for a short period of time (30-40 seconds at maximal effort).
- A by-product of the breakdown of glycogen is lactic acid. High levels of lactic acid within the muscles can lead to muscular fatigue.
- The aerobic system uses mainly glycogen and fatty acids that are oxidised within the mitochondria.
- The by-products of aerobic energy production are carbon dioxide and water.
- The predominant energy system used in exercise is determined by the intensity, duration and type of activity.
- There are specific changes to the energy system for special populations.

# The Cardiorespiratory System

## Introduction

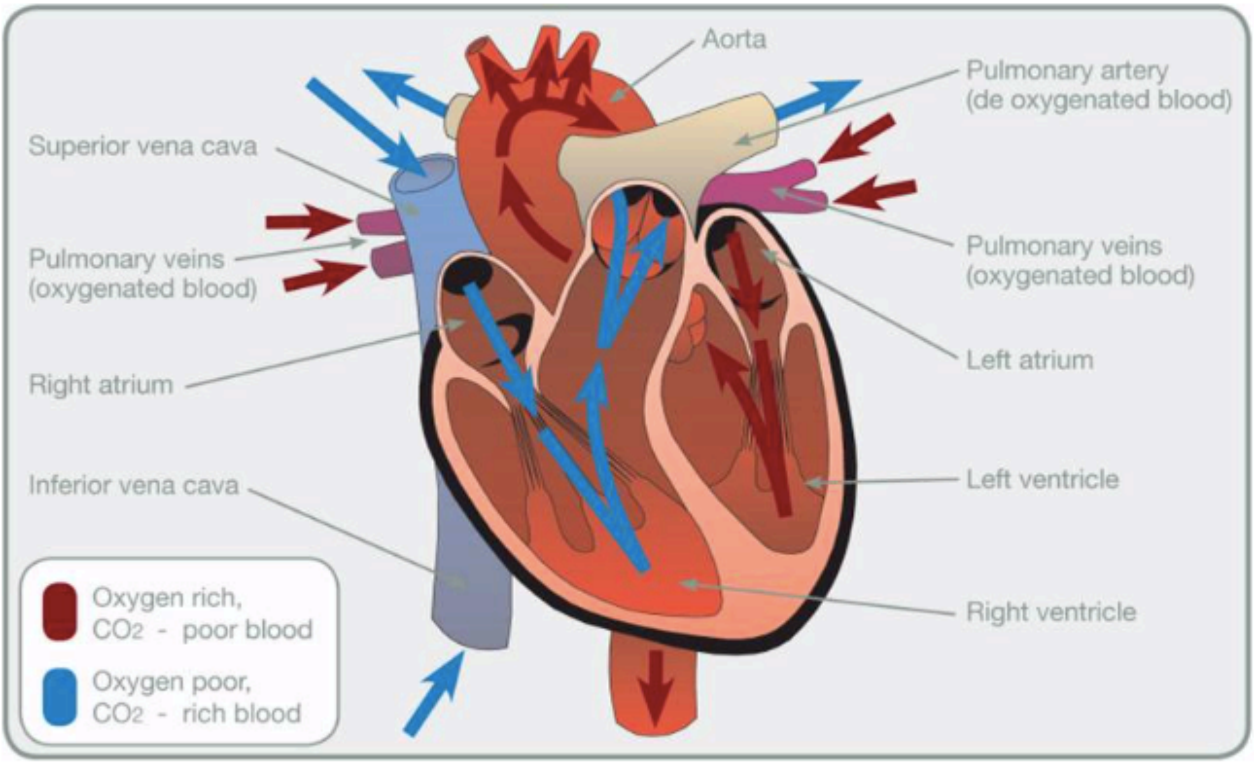
The term 'cardiorespiratory', as it sounds, refers to the heart (cardio) and lungs (respiratory). In this section, we will explore the heart, lungs, as well as the cardiovascular (heart and blood vessels) system. Take a deep breath, and in many respects that is what this section is about, the journey of breath of air through the body during rest and exercise.

## Objectives

By the end of this section, the learner should be able to:

- Identify the location and describe the function and structure of the heart
- Describe how blood moves through the four chambers of the heart
- Explain the function of heart valves
- Describe the coronary circulation
- Describe systemic and pulmonary circulation
- Describe the structure and function of blood vessels
- Explain the effect of the disease process on the structure and function of blood vessels
- Define blood pressure
- Identify blood pressure classifications
- Explain the short- and long-term effects of exercise on blood pressure, including the valsalva effect
- Identify the location, function and structure of the lungs
- Identify the main muscles involved in breathing
- Describe the passage of air through the respiratory tract
- Describe the process of gaseous exchange of oxygen and carbon dioxide in the lungs

**The Heart**




The heart is located posterior to the sternum, just left of centre in the chest. It is about the size of a clenched fist and is responsible for pumping blood around the body. The heart consists of four chambers: two upper atria and two lower ventricles. The walls of the four chambers are made of cardiac muscle, called the myocardium. Coronary arteries, which surround and pierce the heart, deliver oxygen-rich blood to the myocardium, which is necessary for the muscular contraction of the heart.

As illustrated in the diagram, the atria receive blood from the body or lungs and the ventricles pump blood to either the body or lungs.

The left atrium receives oxygenated blood from the lungs via the pulmonary veins. The left ventricle pumps oxygenated blood through the aorta (the largest artery in the body) to the rest of the body. The walls of the left ventricle are thicker than those of the right. This enables the left ventricle to contract more forcefully than the right. Two large veins (inferior and superior vena cava) return de-oxygenated blood from the body to the right atrium. When the right ventricle contracts, de-oxygenated blood is pumped to the lungs.

Heart valves between the atria and ventricles, aortic and pulmonary arteries determine the pathway of blood through the heart and stop the backward flow of the blood.

**The cardiac cycle**
The cardiac cycle is the sequence of events in one beat of the heart (the alternate contraction and relaxation of the heart). The contraction phase is called systole, which causes a volume of blood to be pumped to the arteries. When the heart relaxes, this is called the diastole and blood flows into the heart from the veins. This cycle of events helps to keep the blood moving from the veins through the heart and to the arteries.

**Heart rate**
A healthy adult has a resting heart rate of between 60-80 beats per minute (bpm), whereas a well-conditioned individual tends to have a resting heart rate of around 35-50 bpm. The heart is a muscle and, just as skeletal muscles get stronger when exercised, so does the heart. The muscular walls of the left ventricle can sometimes increase in size, this is called cardiac hypertrophy.

**Stroke volume**
The stroke volume is the amount of blood pumped by a ventricle per heartbeat. A normal stroke volume at rest is between 70-80ml per beat. In well-trained individuals, the stroke volume at rest is 100-110ml per beat. During exercise, the stroke volume increases. In well-trained individuals, values as high as 200ml per beat have been recorded.

**Cardiac output**
Cardiac output is the amount of blood pumped out by the ventricles in one minute. During exercise, cardiac output must increase to meet the body's demand for oxygen.

A simple formula enables cardiac output to be determined:

Cardiac output = stroke volume x heart rate

If an average stroke volume is 71 ml, and an average resting heart rate is 70 bpm, then:
Cardiac output = 71ml x 70 bpm = 4,970ml per minute, or nearly 5 litres of blood

As previously indicated, a key adaptation to a regular endurance exercise programme is that the resting heart rate decreases and stroke volume increases. For example, a well-trained individual whose stroke volume is 100ml and heart rate is 50 bpm has a cardiac output of:
100ml x so bpm = 5.000ml

Cardiac output can be maintained with fewer beats in such individuals.

**Blood pressure**

Blood pressure is defined as the amount of pressure that is exerted on the walls of the blood vessels as blood moves through them. This is vital for driving the circulating blood through the blood vessels to the various places in the body, forcing it through the tiny capillaries, and enabling it to move upwards against gravity.

The pressure of blood flowing through the arteries varies is due to the pumping action of the heart. When the heart contracts, blood is pumped out of the heart and into the arteries under the highest pressure. When the heart relaxes, and before it pumps again, the pressure in the arteries is at its lowest. The pumping and relaxing phases of the heart are referred to as 'systolic' and 'diastolic', respectively. Without this pressure, blood would gravitate, or pool, in the lowest parts of the body.

When blood pressure is measured, this measurement records the pressure in the arteries of these two phases. A typical measurement would be: 'l20/80mmHg.

The first number represents the highest level blood pressure reaches when the heart contracts (systolic) and pumps blood into the arteries. The second number represents the lowest level blood pressure reaches when the heart relaxes (diastolic).

Blood pressure is constantly changing to meet the body's needs. It is normal for it to increase during exercise and to decrease in periods of rest, such as when sleeping. Long-term, regular aerobic exercise can have a normalising effect on elevated blood pressure.

- Systolic pressure - The contraction phase of the myocardium
- Diastolic pressure - The relaxation phase of the myocardium.

**Classifications of blood pressure measurements:**

**Hypotension** - This is low blood pressure and is a reading of <90 systolic over < 60 diastolic

Hypotension is not generally considered a health risk but could be indicative of other health issues. It is most common in those who are young, female, of slight build, fit and vegetarian.

**Normal** - 90-120 systolic over 60-80 diastolic

Normal blood pressure indicates a healthy cardiovascular system, with sufficient pressure to supply all of the organs with blood, but not too high to cause damage.

**Pre high blood pressure** - 120-140 systolic over 80-90 diastolic

Pre high blood pressure is not a contraindication to exercise, but does suggest that lifestyle changes should be advised to prevent the condition worsening.

**Hypertension** - >140 systolic over >90 diastolic

Hypertension is very common. it is most likely in those who are older males, overweight, unfit, stressed and have a poor diet. Chronic hypertension results in a constant strain and battering of the smooth inner artery walls, which is associated with an increased risk of coronary heart disease, stroke, kidney dysfunction and some forms of dementia. High blood pressure often accompanies atherosclerosis and arteriosclerosis.

By managing blood pressure with a healthy lifestyle - and in some cases medication - the risk of associated disease can be decreased.

Blood pressure responses to exercise

| **Short term (during exercise)** | **Long term (after weeks/months)** |
|---|---|
| Systolic blood pressure increases proportionately with exercise intensity. Heavy resistance training will increase it most and therefore is not recommended for those with high blood pressure. | In those with mild hypertension, resting and exercising blood pressures can be reduced by up to 10mmHg with endurance-type cardiovascular activities. |
| Diastolic blood pressure remains largely unchanged. | The time for diastole is increased improving coronary blood flow. |

**The Valsalva effect**
The Valsalva effect/manoeuvre is the holding of breath during exertion. It has been associated with heavy weight lifting. It is performed by moderately forceful attempted exhalation against a closed airway, usually done by closing one's mouth, pinching one's nose shut while pressing out as if blowing up a balloon. This can cause undesirable fluctuations in blood pressure which can be dangerous for those with cardiovascular disease. It should also be avoided during pregnancy.

**Heart valves**

The circulation of blood through the chambers of the heart is maintained as a one way system by a series of non-return valves which prevent any backflow of blood.

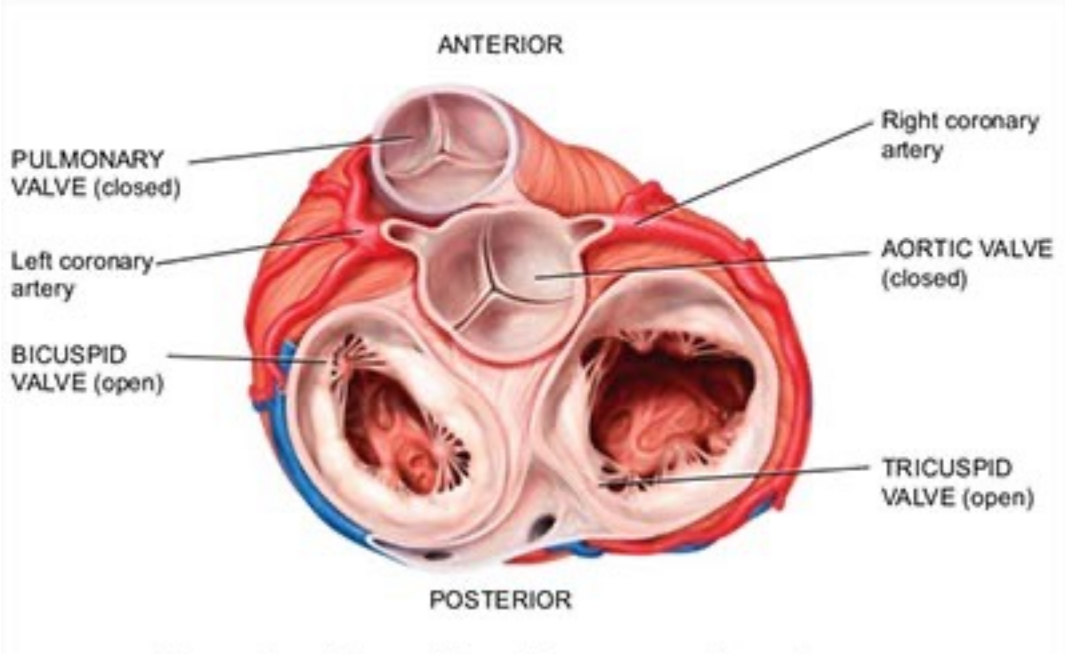
There are two valves between the atria and ventricles - the atrioventricular (AV) valves.

- The right AV valve is the tricuspid valve and prevents backflow of blood from the right ventricle to the right atrium.
- The left AV valve is the bicuspid or mitral valve and prevents backflow of blood from the left ventricle to the left atrium.
- Both are attached to the ventricle walls by collagen cords, the cordae tendinae (the heart strings)
- As blood flows from the atria into the ventricles the valves are loose and fall open into the ventricle chambers. When the ventricles contract the pressure created forces the valves upwards and together to shut and stop any blood being pushed back into the atria.

The other two valves are located between the ventricles and the arteries into which they pump blood. These valves are known as the semilunar valves because they are composed of three moon shaped crescents.

- The pulmonary valve is located between the right ventricle and the pulmonary artery and prevents backflow of blood from the pulmonary artery into the right ventricle.
- The aortic valve is located between the left ventricle and the aorta and prevents backflow of blood from the aorta into the left ventricle.
- As the ventricles fill up, the semilunar valves remain closed to prevent arterial backflow into the ventricles. As the ventricles pump, the pressure causes the semilunar valves to flatten against the walls of the arteries opening to them allow blood to exit the heart.

Heart valves can become damaged, for example by infection, causing them to stiffen and narrow (stenosis). This leads to the heart working harder to get blood out and it can eventually fail. Advanced stenosis requires synthetic valve replacement.



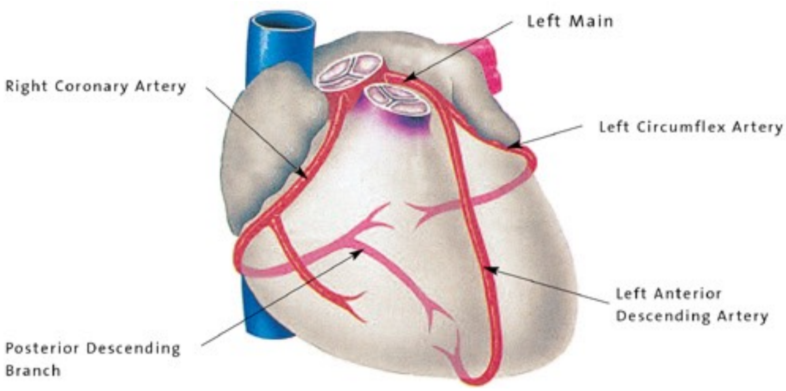

**The coronary arteries**

The heart is a muscle and it requires a blood supply that is rich in oxygen in order for it to contract. The blood supply for the heart is supplied by the coronary arteries. These arteries keep the myocardium supplied with oxygen.

There are two coronary arteries; one on the left side of the heart and one on the right side.

The left coronary artery has two main branches:

- The left anterior descending artery supplies the anterior portion of the left atrium and ventricle with oxygenated blood.
- The left circumflex artery supplies the posterior portion of the left atrium and left ventricle with oxygenated blood.
- The right coronary artery supplies the right atrium and right ventricle with oxygenated blood



Each of these arteries has many other branches.

The myocardium has virtually no anaerobic capacity so it relies on the oxygen-rich blood supply from the coronary arteries to function. The diastole phase (recovery phase of the cardiac cycle) is when the arteries are able to fill with oxygen-rich blood most effectively. The time for this phase decreases with higher heart rates. During the pumping phase (cardiac systole), the coronary arteries are compressed, restricting blood flow to them.

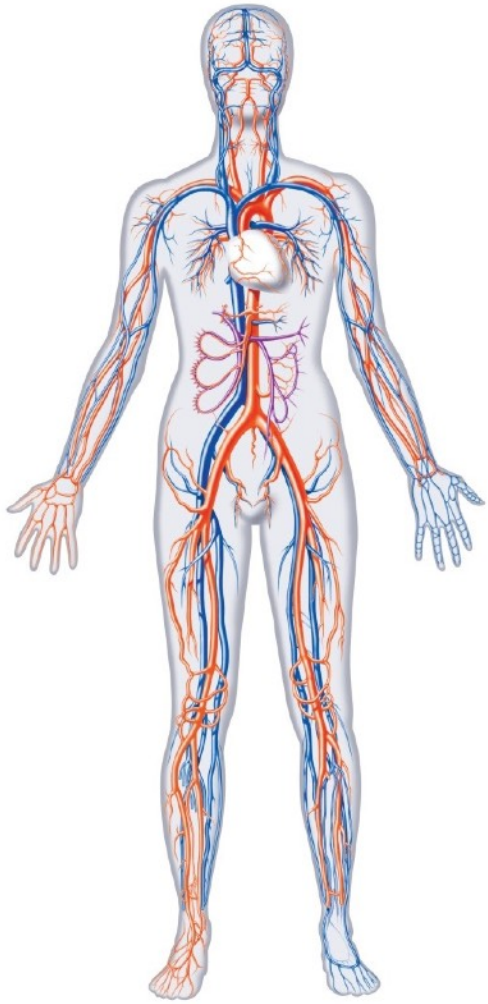
Once the blood has passed through the capillary beds of the myocardium, the blood flows into the coronary veins, which join together to form the coronary sinus. This blood vessel empties blood into the right atrium, where it joins the deoxygenated blood returning to the lungs for re-oxygenation.

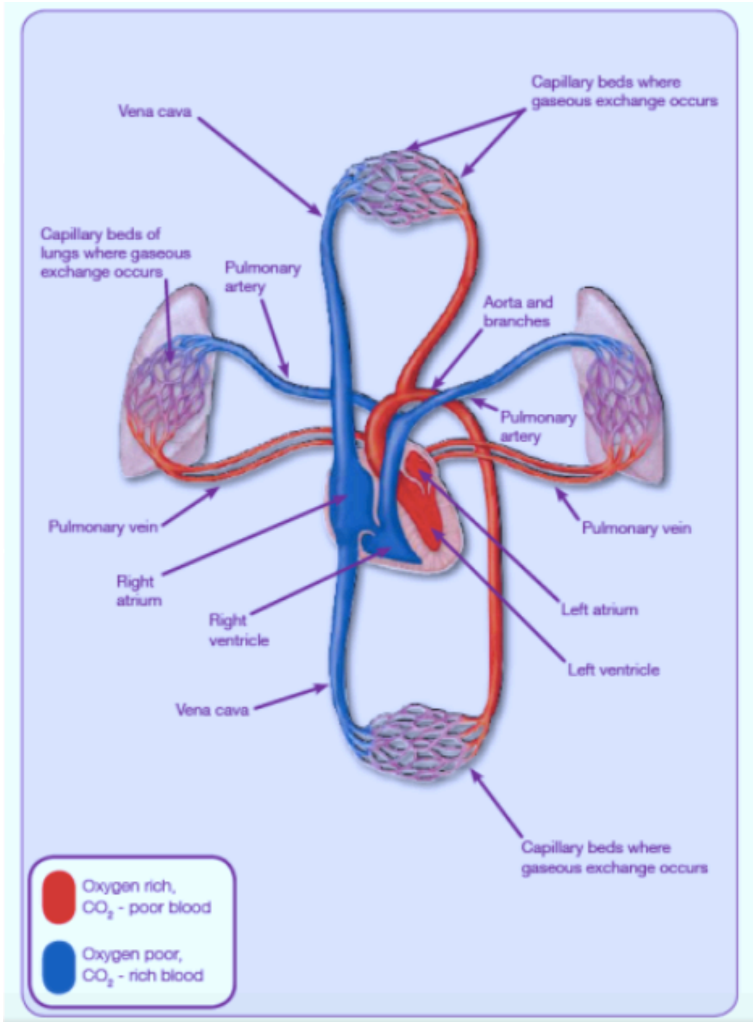
With regular cardiovascular activity, both resting and working heart rates decrease. This leads to increased time for diastole and allows for greater filling of the coronary arteries. This improves coronary blood flow to the myocardium both at rest and during activity.

**Key points for the heart**

- The heart is a two~sided pump with four chambers.
- The right atrium receives de-oxygenated blood from the veins of the body.
- The right ventricle pumps de-oxygenated blood to the lungs via the pulmonary arteries.
- The left atrium receives oxygenated blood from the lungs via the pulmonary veins.
- The left ventricle pumps oxygenated blood to the body via the aorta.
- The cardiac cycle consists of two phases: systole (the contraction phase) and diastole (the relaxation phase).
- Blood pressure ensures that circulating blood reaches all parts of the body and moves upwards, against gravity.
- Stroke volume is the amount of blood pumped out by the ventricles in one contraction.
- Cardiac output is the amount of blood pumped out by the ventricles in one minute and is a product of heart rate and stroke volume.
- The heart receives oxygen-rich blood from the coronary arteries.
- The heart adapts to regular endurance training by decreasing the resting heart rate and increasing the stroke volume. Hence, the cardiac output can be maintained with fewer beats.

**The vascular/circulatory system**






The vascular, or circulatory, system consists of the arteries and veins through which the heart pumps blood throughout the body.

The prime purpose of the vascular system is the transport and exchange of materials (oxygen, carbon dioxide, nutrients, hormones, heat, metabolic waste products and protective white cells) between the blood and tissues, which takes place in the capillaries.

**Blood**

Blood is a mixture of blood cells carried in a liquid called plasma. Two types of blood cells are particularly important. Red blood cells transport oxygen, and white blood cells are important to the immune system. Blood also carries nutrients, hormones and medicines.

## Blood vessels

### Arteries

The arteries carry blood from the heart to the capillaries. Arteries become progressively smaller, becoming arterioles as they reach the tissues.

Arteries are characterised by their thick muscular walls, made up of smooth muscle and elastic connective tissue, which assist in the maintenance of blood pressure. Following ventricular contraction, the pressure and recoil of the artery wall contributes to blood pressure. The pressure in the large arteries is very high, but diminishes as the arteries become smaller and get further away from the heart. Without this pressure, blood would gravitate to the lowest parts of the body. Blood pressure enables the circulating blood to move upwards against gravity to supply blood to the brain, as well as forcing blood through the tiny capillaries.
Remember, that in general, the 'A' in the arteries is useful to remember as 'Away' from the heart. Arteries transport oxygenated blood away from the heart. The only exception to this rule is the pulmonary artery, which transports de-oxygenated blood to the lungs, but it still carries blood away from the heart.

### Veins

Veins carry blood under low pressure from capillaries back to the heart. Smaller veins are called venules. The walls of veins are made up of smooth muscle and connective tissue. The key ways in which veins differ from arteries are that they have thin fibrous walls and one-way valves at regular intervals to prevent the backflow of blood.

Remember this: the pulmonary vein transports oxygenated blood from the lungs to the heart; all other veins carry de-oxygenated blood.
Venous return is the amount of blood that is returned to the heart by the veins. The heart can only pump the blood that it receives. If venous return decreases, the heart contracts less forcefully, causing a decrease in blood pressure.

### Capillaries

Capillaries carry blood from arterioles to venules. The capillary walls are only one cell thick. It is in the capillaries that the exchange of materials between the blood and tissues takes place. The process by which this exchange occurs is called diffusion.

Recall that the walls of the blood vessels are made from smooth muscle and connective tissue. With increasing age (as well as some illnesses and disabilities), blood vessels become less elastic and therefore less efficient carriers of blood. One example of this is when vessels become susceptible to atherosclerosis. This is when the inner walls of arteries become coated in places with atheromatic plaques: cholesterol-containing material that occludes the vessels, preventing efficient blood circulation. Since the functioning of all tissues is dependent on good blood circulation, these factors have widespread effects on this system.

### Diffusion

Diffusion is the movement of molecules from an area of greater concentration to an area of lesser concentration. Within the body, oxygen and carbon dioxide move by diffusion. An example of this is in the lungs, where there is a low concentration of oxygen in the blood of the pulmonary capillaries. The opposite is true for carbon dioxide. in this case, oxygen diffuses into the capillary and carbon dioxide diffuses across the capillary membrane and into the lungs. In each case, the gases move from where there is more to where there is less.

Diffusion that occurs in the exchange of gases (oxygen and carbon dioxide) within the lungs is also known as gaseous exchange.  In the capillaries within muscles, oxygen diffuses from the blood (high concentration)  to the tissues (low concentration), while carbon dioxide diffuses from the tissues (high) to the blood (low) to be brought back to the lungs and exhaled.

## Circulation

The vascular system has two major pathways of circulation. These are pulmonary (lungs) and systemic (body).

### Pulmonary circulation

Pulmonary circulation is the flow of blood from the right side of the heart to the lungs and then back to the left side of the heart.

The right ventricle pumps de-oxygenated blood via the pulmonary arteries to the lungs. Pulmonary diffusion then takes place in the lungs. Carbon dioxide is exhaled and oxygen is inhaled. This exchange takes place via the pulmonary capillaries. The capillaries unite to form venules and then veins and finally to form the two pulmonary veins from both lungs that return oxygenated blood to the left atrium.

### Systemic circulation

Systemic circulation is the flow of blood from the left side of the heart to all parts of the body and then back to the right side of the heart.

The left ventricle pumps blood via the aorta into the arteries, arterioles and capillary networks throughout the body. The capillaries merge to form venules and veins. The veins return blood to the right atrium.

## Circulatory disease

There are two main forms of disease that can affect the arteries.

**Arteriosclerosis** - This is a progressive degeneration of the arterial walls that leads to hardening and loss of elasticity. The ability of arteries to relax and allow more blood to pass through is decreased and often leads to high blood pressure. It is associated with ageing and is sometimes known as hardening of the arteries.

**Atherosclerosis** - The progressive narrowing of arteries caused by circulating fats (lipids) being deposited In the lining of the artery walls that have become rough. These plaque/fatty deposits are known as atheroma. Calcium is also laid down around these deposits further leading to arteriosclerosis.

As the arteries narrow it becomes increasingly difficult to meet the oxygen demand of the organs and muscles. When the demand for oxygen outweighs the supply - for example when an individual exercises - the muscle or organ is deprived of oxygen and this results in pain.

When the coronary arteries are affected by arteriosclerosis and atherosclerosis it is known as coronary heart disease (CHD). The imbalance of oxygen demand and supply is known as myocardial ischaemia and typically results in chest pain commonly known as angina.

**Risk factors**

There are several risk factors that will affect an individual's risk of developing circulatory disease. The risk factors include:

Non-lifestyle factors

- family history
- age

Lifestyle factors

- smoking
- environment
- physical inactivity - sedentary lifestyle
- diet eg, high levels of saturated fats and cholesterol
- hypertension
- type 2 diabetes
- obesity/overweight
- high blood cholesterol (blood lipid profile ratio of high density lipoproteins and low density lipoproteins)
- stress
- hormone replacement therapy.

Simple lifestyle changes can help decrease the risk of disease, for example increasing physical activity. A long-term adaptation to regular endurance exercise is a decrease in resting and exercising heart rates. This increases the time for diastole and improves coronary blood flow allowing oxygen demands of the myocardium to be met more effectively.

Controlling body weight, giving up smoking, eating a healthy diet low in saturated fats and managing stress levels are all ways to help reduce the risk of circulatory disease.

**Cardiovascular responses to exercise**

The adaptations that occur in the cardiovascular system all result in an increased efficiency of oxygen and blood supply at rest and during exercise.

| Short term (during exercise) | Long term (after weeks/months) |
|---|---|
| Heart rate increases in proportion to intensity; this enables higher levels of oxygen to be delivered to working muscles and more carbon dioxide to be removed. When exercise progresses past 30 minutes the heat related loss of water and electrolytes from the blood results in a steady upward drift of heart rate (cardiac drift). Adequate hydration before and during exercise can help minimise cardiac drift. | Heart rate decreases and post-exercise recovery times improve. A trained person's resting heart rate is typically 52 beats per minute, whereas an untrained average resting heart rate is around 72 beats per minute. |
| Stroke volume increases. | Stroke volume increase due to stronger myocardium. |
| Cardiac output increases by as much as 20 I/min in a sedentary individual and 40 l/min for trained individuals. | Increased cardiac output at a lower heart rate. |
| Blood flow is diverted away from areas such as the intestines by vasoconstriction (narrowing) of the arteries to divert blood to the working muscles to meet the increased oxygen demands of activity. | Improved blood supply to the myocardium due to increased time for diastole as a result of reduced heart rates at work and rest. |
| Vasodilation widens the arteries and arterioles supplying the muscles to enable an increased blood flow. Vasoconstriction narrows the arteries, decreasing the blood supply to the intestines. Sphincter valves open and close capillary beds in the muscles. | lncreased blood volume. |
| Increased oxygen supply to meet demands of exercise. | Increased red blood cell count. |
| Increased coronary blood flow from approximately 250 cubic centimetres per minute to approximately 1000 cubic centimetres per minute. | lncreased haemoglobin levels improving oxygen carrying capacity of the red blood cells. |
| | Improved 'tone' in the smooth muscle of the artery walls increasing their ability to expand and contract to move blood. |
| | More efficient circulation. |
| | Hypertrophy of the myocardium especially the left ventricle. |
| | Improved blood cholesterol profile reducing the risk of CHD. |
| | lncreased capillarisation allowing for improved gaseous exchange in the muscles and lungs. |
| | Decreased risk of coronary heart disease and other diseases such as type II diabetes. |

In addition to cardiovascular responses to exercise the respiratory system also adapts and is closely connected to the cardiovascular system through the system of capillaries surrounding the alveoli. The main adaptations are to the respiratory volumes.

**Tidal volume**

Tidal volume is the amount of air moved in and out of the lungs in one breath. When exercise begins, tidal volume increases to meet the increased oxygen demands of the activity and to remove the increased levels of carbon dioxide being produced through aerobic metabolism.

With long-term exercise the muscles of breathing become more efficient and breathing rate decreases while tidal volume increases. This allows for an improved exchange of gases both at rest and during activity.

**Residual volume**

Residual volume is sometimes known as the ’dead space’ in the lungs. It is the amount of air left in the lungs after exhalation. It is needed to allow gaseous exchange to continue between breaths and keeps the lungs inflated.

When exercise begins residual volume will decrease. This is due to the increased tidal volume (more air moving in and out of the lungs in each breath).

As a long-term adaptation residual volume will decrease at rest, again due to the increase in tidal volume allowing for a greater amount of air to be moved in and out of the lungs in one breath.

Residual volume and tidal volume have an inverse relationship. If tidal volume increases, residual volume decreases and vice versa.

**Vital capacity**

Vital capacity is the maximum amount of air that can be forcefully inhaled and exhaled in one breath. As tidal and residual volumes improve with regular activity, vital capacity can increase.

Respiratory responses to exercise

| **Short term (during exercise)** | **Long term (after weeks/months)** |
|---|---|
| Increased breathing rate | Decreased breathing rate |
| Increased tidal volume | Increased tidal volume |
| Decreased residual volume | Decreased residual volume because of the increased use of dead space |
| Increased efficiency of carbon dioxide removal and oxygen uptake | Increased efficiency of carbon dioxide removal and oxygen uptake |
| | Increased capillarisation, improving gaseous exchange |
| | Increased vital capacity |

**Benefits and risks of cardiovascular exercise**

Regular cardiovascular endurance exercise will bring about both long- and short-term changes in the heart, lungs and circulatory system.

Other benefits of cardiovascular exercise include:

- improvements in everyday function
- increases in bone density especially in areas placed under load from impact activities
- reduction of body fat and maintenance of body fat levels within healthy ranges
- decreased risk of CHD, type 2 diabetes and other diseases.

While the benefits of activity are numerous, any mode of exercise carries with it associated risks. While careful programming and health screening can help to minimise these risks, they cannot always be avoided altogether. It is important to inform those considering participation in an exercise programme of both the benefits and risks involved.

These risks include:

- increased risk of muscle strain
- increased risk of skeletal/joint injury
- increased risk of connective tissue damage
- increased risk of muscle imbalances in certain modes of exercise eg, tight hamstrings in runners and cyclists
- increased workload on the heart, which for some individuals is dangerous
- increased levels of carbon dioxide production
- increased lactic acid production
- decreased levels of body fat below recommended levels for some athletes, which can increase the risk of osteoporosis.

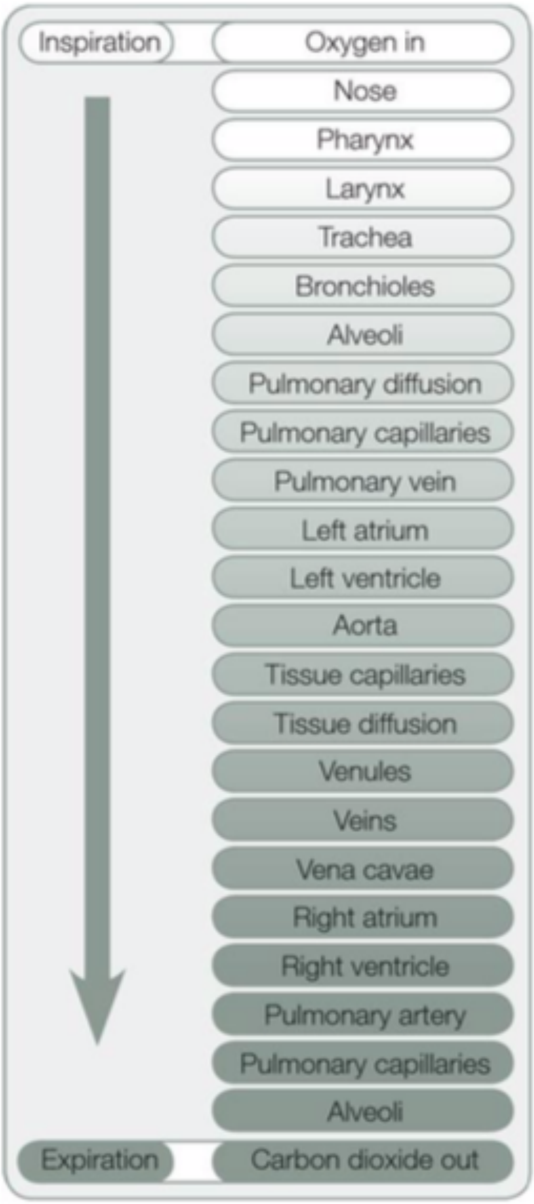
### Key points of the vascular system

- The vascular system transports and exchanges materials (oxygen, carbon dioxide, nutrients, hormones, heat, etc.) between blood and tissues.
- Arteries have thick muscular walls and, in general, transport oxygenated blood from the heart to the capillaries.
- Veins have thin muscular walls and, in general, transport de-oxygenated blood, under low pressure, from capillaries back to the heart.
- Oxygen and carbon dioxide transfer occurs in the lungs and tissues by diffusion.
- Pulmonary circulation is the movement of blood from the right side of the heart to the lungs and then back to the left side of the heart.
- Systemic circulation is the movement of blood from the left side of the heart to the body and then back to the right side of the heart.

**The Respiratory System**

The respiratory system is involved in breathing, that is, the movement of air in and out of the lungs. The lungs are located in the chest either side of the heart. They are the site for the exchange of oxygen and carbon dioxide between air and blood. All human cells must obtain oxygen to carry out cell respiration in order to produce ATP (aerobic energy system - see previous unit) and eliminate carbon dioxide, which is its waste product.

The oxygen used by the body is derived from the air we breathe. Pure, dry air contains 78% nitrogen, 21% oxygen and traces of other gases. Normal air usually also contains water vapour, dust pollen, germs, poisonous gases and other pollutants and the carbon dioxide content is near to 0.04%.



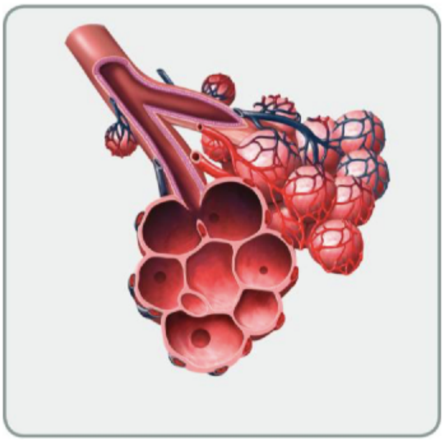

Air enters and leaves the respiratory system via the nose or mouth. Nasal breathing is better for the body because air is warmed and filtered in the nasal cavities.

From the nose or mouth, the air then passes through the pharynx, or throat. This lies behind the nose and mouth and both cavities open onto it. From here, it goes to the larynx, often also called the voice box. The cavity of the larynx is separated from the pharynx by a flap, called the epiglottis, which prevents food from entering the trachea, or windpipe, and into the lungs.

The trachea is cylindrical, 10-13cm in length and kept open by a series of rings of cartilage. At its lower end, the trachea divides into two bronchi. One bronchus leads to each lung, and this then breaks up into even smaller bronchioles. The bronchioles terminate in clusters of alveoli (often called air sacs) which are surrounded by pulmonary capillaries, the site of gaseous exchange (pulmonary diffusion).

In the young, these structures are extremely sensitive. Any inhaled debris would usually cause vigorous coughing to expel it. However with age, they become less sensitive, so a coughing reflex may not be initiated in response to inhaled material. This increases the chance of irritants reaching the lungs.

### The Alveoli



The alveoli are the functional units of the lungs, and there are millions of alveoli in each lung. A network of pulmonary capillaries, in which diffusion takes place, surrounds each alveolus. Carbon dioxide passes through the single cell walls into the alveolus to be breathed out while oxygen passes into the capillary from the alveolus. This oxygenated blood is then collected into veins and returned to the left atrium by the pulmonary vein.

As a person ages, there is a reduction in the number  of alveoli. Gradually, they begin to take on a flattened appearance resulting in a reduction in the alveolar surface area available for diffusion to take place.

### The Breathing Action

Breathing is the result of the movement of the ribcage and changes in volume and pressure in the alveoli. The main respiratory muscles are the diaphragm and the internal and external intercostals.

The diaphragm is a dome-like muscle situated below  the lungs. It flattens when it contracts, increasing the capacity of the chest cavity. At the same time, the contents of the abdomen are pushed downwards, causing a slight forward bulge.

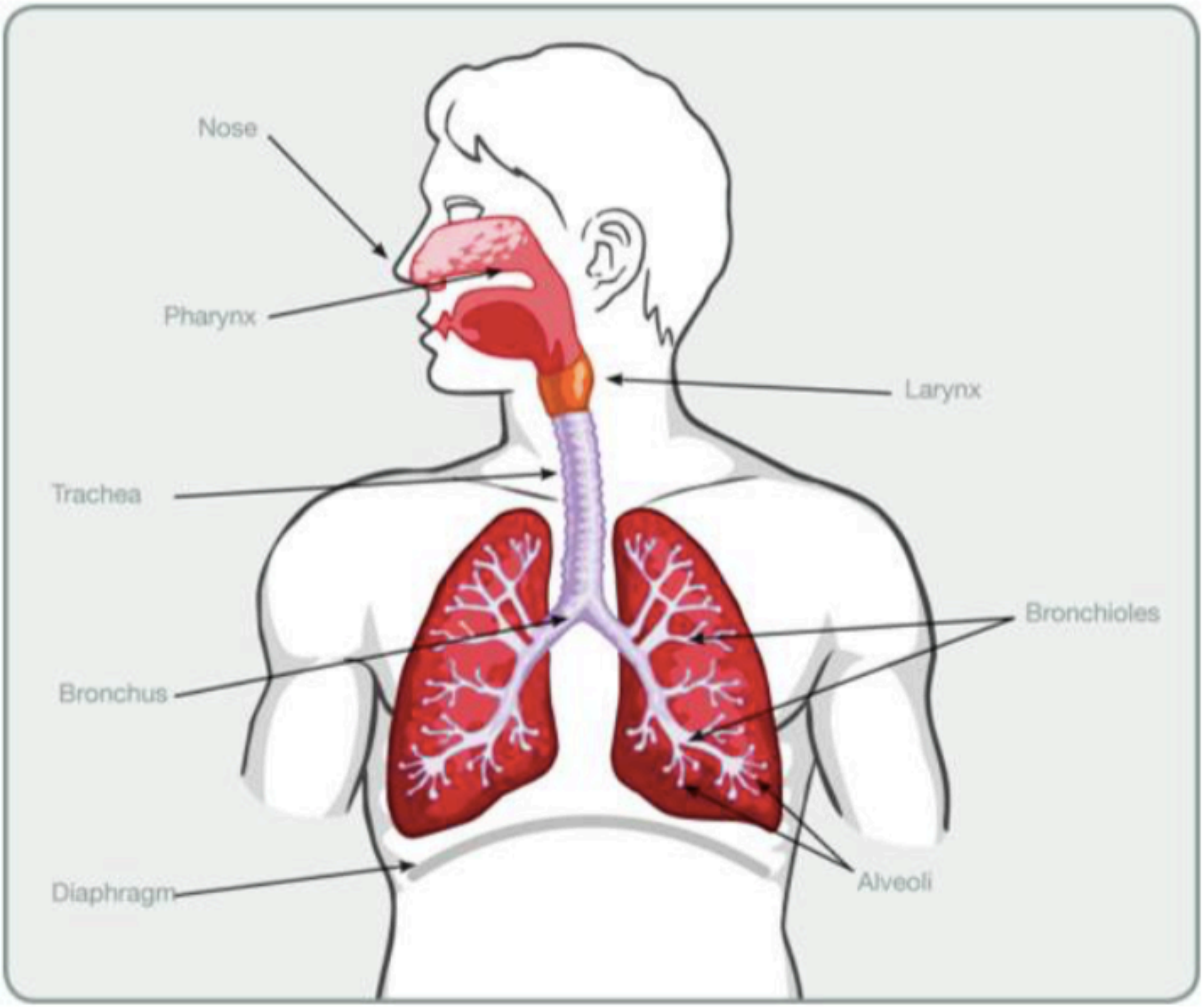
The intercostal muscles are found between the ribs. The external intercostal muscles pull the ribs upwards and outwards. The internal intercostal muscles pull the ribs downwards and inwards.

Inspiration, or inhalation, occurs when the diaphragm contracts, moves downwards and expands the chest cavity. The external intercostal muscles pull the ribs upwards and outwards. The alveoli expand and air is taken into the lungs.

Expiration, or exhalation, occurs when the diaphragm and external intercostals relax. As the chest becomes smaller, the lungs are compressed and their elastic connective tissue recoils and compresses the alveoli, forcing air out.

In the young, the chest wall is relatively supple and elastic, thereby providing an efficient breathing action. With increased age, there is a gradual increase in rib calcification and gradual age-related reduction of the respiratory muscles.

As a result of these changes, the process of breathing becomes less efficient. This is particularly apparent  individuals who have been inactive, which we know promotes muscle wastage and weakness.




The content of exhaled air will change due to the requirements of the body. Oxygen levels will drop to approximately 16% as the body uses oxygen to produce energy via the aerobic energy system. Nitrogen and the other rare gasses remain the same, while carbon dioxide levels increase to 4%, due to the production of carbon dioxide during aerobic energy production.

Breathing goes on continuously and, for much of the time, unconsciously. It is controlled by the respiratory centre of the brain, which responds very quickly to slight changes in the carbon dioxide concentration in the blood. Even a small increase in the carbon dioxide level can greatly increase the volume of air breathed in and out. Lack of oxygen also affects the breathing rate, but this is detected mainly by sensors in the large blood vessels in the neck.

At rest, the breathing rate is normally about 12-14 breaths per minute and the tidal volume (amount of air involved in one normal inspiration and expiration) is about 0.5 litres, or roughly 6-7 litres per minute.

The capacity of the lungs varies in accordance with the size and age of the person. Taller people tend to have larger lungs than shorter people. As we age, the elasticity of the lungs diminishes, thereby reducing their ability to recoil, impairing the lungs' ability to suck in and push out air.

**Special populations and the cardiorespiratory system**

**Children**
Children have a decreased blood volume in comparison to adults. Among other factors, this is one of the reasons why children are less efficient at temperature regulation and heat up faster and overheat more easily than adults.

Children's heart chambers are smaller and less powerful than adults'. For this reason, their maximum heart rate (MHR) is higher and the stroke volume of the heart is less. They are less efficient at processing oxygen and require a high uptake of oxygen for aerobic activity, as well as having a limited ability at working anaerobically.

**Pregnancy**
Pregnancy also affects the respiratory system.

During pregnancy, blood volume increases by approximately 30%. Blood becomes more dilute, with fewer red blood cells. Stroke volume and cardiac output increase as a result of the extra muscle tissue laid down within the heart (due to the influence of oestrogen). Resting heart rate increases by approximately 10-15 beats per minute, also contributing to increased cardiac output. Blood vessels are dilated by the relaxing effect of progesterone. Venous return can be reduced due to the foetus pressing on the blood vessels of the pelvic area.

The oxygen requirement of the foetus increases gradually to 20% from the 18th week of pregnancy to meet the additional needs of mother and foetus. At this time, carbon dioxide receptors in the brain also become more sensitive. This results in pregnant women becoming more breathless; some may even hyperventilate. Lung volume changes and breathing deepens. The diaphragm is forced up in the later stages of pregnancy, resulting in reduced total lung capacity. The ribs move upwards and outwards by 10-1 5cm to assist breathing.

During this period, supine hypotensive syndrome occurs when lying on the back. This is when the uterus presses on larger blood vessels, reducing venous return and cardiac output, leading to dizziness, loss of consciousness and a reduction of blood supply to the foetus.

**Ageing**
It has been reported that from 30-70 years of age, the cardiovascular system shows a decline of 30%. Certain physiological changes are inevitable with age, but some of the changes that occur are actually due to a lack of activity that often accompanies ageing. Regular exercise can slow the physiological changes of ageing by as much as 50%. It is therefore conceivable that an active 60-year-old can have a more efficient cardiovascular system than an inactive 25-year-old.

Some of the main age-related changes to the respiratory system are as follows:

- decreased cardiac output
- reduction in VO2 max
- decreased maximum heart rate (MHR)
- reduced efficiency of the circulatory and respiratory systems as a result of specific changes to its many components
- increased blood pressure

- reduced tolerance to lactic acid and fatigue.

**Disability**
There are a range of medical conditions and disabilities that have an impact on the function of the cardiovascular and respiratory systems specific to each individual.

**Key points for the respiratory system**

- The pathway by which air travels to the lungs is: nose - pharynx - larynx - trachea - bronchus - bronchioles - alveoli.
- Gaseous exchange occurs in the capillaries of the alveoli. Carbon dioxide is breathed out, and oxygen is taken in.
- The pathway by which oxygen is taken to the heart is: alveoli - capillaries - pulmonary vein - left atrium.
- Oxygen combines with haemoglobin in the red blood cells for transportation. The main respiratory muscles are the diaphragm and intercostals.
- Breathing is controlled by the respiratory centre of the brain and is determined by the concentration of carbon dioxide in the blood.

# The Neuroendocrine System

## Introduction

The nervous system acts as the communication system within the human body. It controls the actions of bodily systems by responding to incoming information. It works with the endocrine system to maintain 'homeostasis' within the human body.

## Objectives

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

- describe the specific roles of the central nervous system (CNS) and peripheral nervous system (PNS)
- describe the nervous control and transmission of nervous impulses
- describe the structure and function of a neuron
- explain the role of a motor unit
- explain the process of motor unit recruitment and the significance of a motor unit's size and the number of muscles fibres
- explain the function of muscle proprioceptors and the stretch reflex
- explain reciprocal inhibition and its relevance to exercise
- explain the neuromuscular adaptations associated with exercise/training
- explain the benefits of improved neuromuscular coordination/efficiency to exercise performance
- describe the functions of the endocrine system
- identify the major glands in the endocrine system
- explain the functions of hormones, to include:
    - growth hormones
    - thyroid hormones
    - corticosteroids
    - catecholamines
    - insulin
    - glucagon.

**The Nervous System**

The central nervous system is the main control centre of the body . This is where all the information that has been sent from the other systems of the body is collected and analysed, in preparation for a response. The central nervous system includes the brain and the spinal cord.

The brain weighs approximately l.5kg (about 3 lbs) and comprises two main lobes, the right and left cerebral hemispheres.

The cerebral hemispheres comprise sensory motor and association areas. The sensory areas are responsible for receiving impulses from the sense organs (eyes, nose, mouth and ears) via the peripheral nervous system. The association areas are connected with memory, thoughts and emotions. The motor areas activate the body systems by sending messages back via the peripheral nervous system.

The nervous system and the endocrine system are the body's systems for sending messages.

The human body works on a principle of homeostasis (meaning 'same state'), which means that physiological settings must be kept in an almost constant state, within a relatively narrow range. The general ranges are common to all, but genetics means that there are slight differences between individuals. If any one level changes outside the range for an individual, then the ability to survive is put at risk.

As an individual goes about their life, the environment within which they interact is constantly changing. This affects the body. For example, changes in temperature and humidity affect body temperature and fluid levels, and eating changes blood sugar levels. The body has a certain ability to adapt to these challenges by sending messages to create appropriate responses, and so return the body to its constant state.

The nervous system is the body's electrical messenger system. It is fast acting in its ability to send messages, usually taking less than one second.

The role of the nervous system is to monitor changes in the internal and external environment. The message received as a result of these changes needs to be interpreted so that the appropriate motor response can be made.

The three main functions of the nervous system are:

- sensory input - monitoring events and changes inside and outside the body -
- interpretation - analysing the data
- motor output - response to the incoming data.

**The two branches of the nervous system**

**The central nervous system (CNS) - the brain and spinal cord**
The central nervous system is made up of the brain and spinal cord. It is constantly receiving messages about changes in the internal and external environment, interpreting and collating the information and deciding on the correct response.

The brain is responsible for interpretation of messages and the spinal cord is responsible for the transfer of messages in and out of the CNS.

**The peripheral nervous system (PNS)** - all the incoming nerves which send incoming information to the CNS and outgoing nerves sending out a response from the CNS.

The PNS is made up of all the nerves that carry sensory information from the body to the CNS (afferent nerves) and the motor nerves that carry response information out to the muscles and organs (efferent nerves).

The sequence of nervous system activity can be described as ACE:

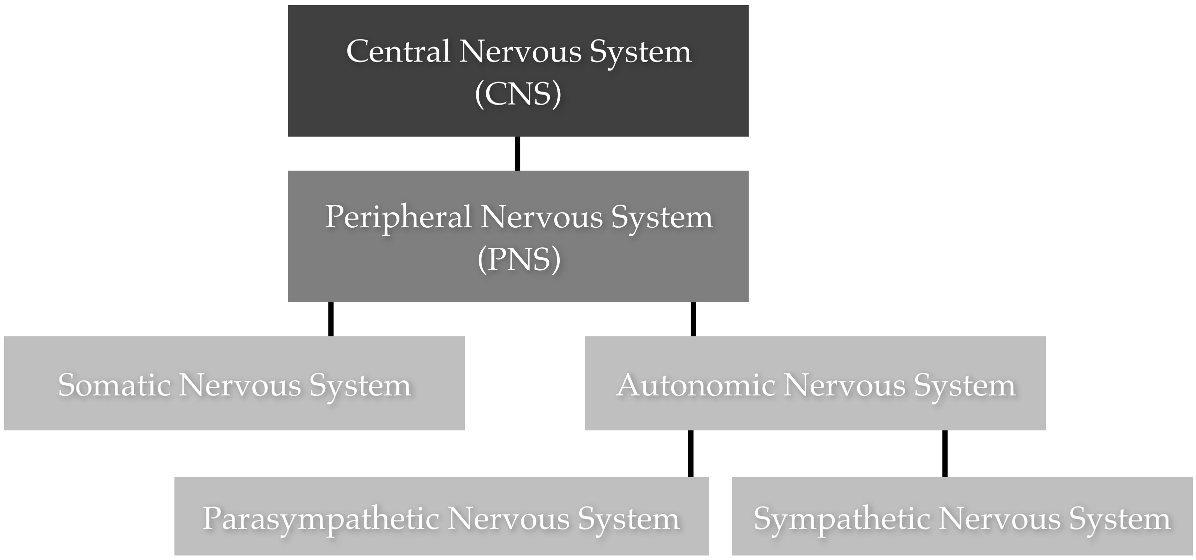
- Afferent - incoming information about changes
- CNS - interpretation and decision making
- Efferent - outgoing information about a response

The peripheral nervous system is responsible for all other nerve processes that branch out from the spinal cord and connect with receptors in the muscles, glands, blood vessels and organs.

There are 31 pairs of nerves that extend from the central nervous system. These supply all other parts of the body and form either the somatic or autonomic branches of the peripheral system.

The somatic part of this system is responsible for all voluntary actions, meaning those over which we have direct control (eg, contracting a muscle to lift a weight). The somatic nervous system regulates voluntary body movement through control of skeletal muscles. It senses movement, touch, pain, skin temperature etc.
The autonomic branch is responsible for all involuntary actions, meaning those over which we have no control (eg, digesting food, reflex actions and cardiorespiratory and gland function).

The autonomic branch of this system can itself be subdivided into the parasympathetic and sympathetic nervous systems. This is ultimately where the balance, or the homeostasis, of the body takes place. For example, when the heart rate needs to be increased to pump more blood around the body during exercise, this is the responsibility of the sympathetic nervous system. The sympathetic system is the accelerator - it speeds everything up. The parasympathetic system, on the other hand, acts as the brakes. For example, during the cool-down phase of an exercise programme, when less blood is required, the parasympathetic system brings about a reduced heart rate.




**Sensory receptors**

Sense receptors or organs detect changes in the internal and external environment.

Sensors for changes in the external environment include those of sight, hearing, touch, smell taste and pain (somatic).

Sensors for changes in the internal environment operate through the autonomic nervous system

These sensors include:

- chemoreceptors - present throughout the body to detect changes in levels of chemicals such as carbon dioxide for respiration and calcium for muscle function
- thermoreceptors - present in all tissues to detect temperature changes
- baroreceptors - found mainly in the walls of the arteries to detect changes in blood pressure
- proprioceptors - found in muscles and tendons to detect changes in body position.

If a message is sent along an afferent nerve to show that levels are outside normal range, this information is interpreted by the brain and a response is sent along the efferent nerve to re-establish the natural balance of the body (homeostasis).

The response could be to adjust body position to avoid a fall or to release a hormone to re-establish a chemical balance, such as glucose levels in the blood.

Efferent nerves that are responsible for creating movement by stimulating muscles to contract are called motor nerves/neurons. These are under the control of the somatic nervous system (conscious control). With regular exercise the number and sensitivity of receptors on the muscle cells increases, making it quicker and easier to make muscle cells respond to a stimulus. This will increase all areas of motor skills including balance and coordination. This is sometimes referred to as 'hard wiring' the nervous system.

**Proprioceptors**

Muscles have specialised sensory receptors that continually monitor the degree of stretch or tension in a muscle and relay that information back to the spinal cord and the brain. Information coming from all muscles in the body is coordinated to give the brain an accurate and precise picture of the spatial arrangement of the body. The brain, via the spinal cord, then sends messages to the muscles to either relax or contract a little more or a little less so that correct posture and body position can occur. All of the muscles of the body are continually stimulated in this way, without our being consciously aware of the on-going process.

Proprioceptors are also useful in the facilitation of stretching techniques. By creating a specific stimulus to activate the proprioceptors the body can elicit a response that can be advantageous to improving flexibility.

There are two proprioceptors that detect changes in the muscles and tendons:

- Muscle spindles - found in the belly of the muscle and detect excessive lengthening
- Golgi tendon organs - found in the tendons and detect excessive tension/contraction.

**Muscle spindles**

Muscle spindles are responsible for initiating the stretch reflex. They provide information on how fast a muscle is lengthening. This information is sent to the spinal cord via the afferent nerve where it is interpreted. The faster the speed of stretch, the more rapid the nerve conductance back into the spinal cord. A simple reflex arc is then initiated, whereby motor neurons are activated and stimulate the muscle to contract. Simultaneously, motor neurons going to the antagonist muscle are inhibited so that it relaxes and cannot interfere with muscle shortening.

This is easily seen when someone falls asleep sitting up. As the head falls and the muscles of the neck lengthen quickly the muscle spindles are activated. The response is to tell the muscles to contract and lift the head to prevent an injury.

Although the stretch reflex is designed to protect the muscle and its connective tissues from damage, it can be exploited to elicit maximal contractions, and therefore power, in muscle action. Plyometrics involves jumps that overstretch the calf and thigh muscles on landing, stimulating the stretch reflex. The subsequent strong contraction provides the power to leap.

It is this stretch reflex that can also increase the risk of injury during ballistic stretching. As the muscle is lengthened quickly through the bouncy, rapid nature of the stretch, the muscle spindle is activated and powerful stimulation of the stretch reflex results. A forceful contraction is brought about at the same time as the individual tries to stretch. This can result in muscle and/or tendon injury.

When a developmental stretch is carried out, the initial tension felt is a result of the muscle spindles being activated. When the stretch position is held, the stimulation of the muscle spindles reduces and muscle tension is decreased. This allows an individual to stretch further until the tension returns and the process can be repeated.

**Golgi tendon organs (GTO)**
Golgi tendon organs are responsible for detecting excessive muscle tension or contraction and work in the opposite way to the muscle spindles. This is sometimes referred to as the inverse stretch reflex.

When a muscle contracts, the force of the contraction is transferred through the tendon to the bone. If a muscle contraction is too strong, it puts the muscle tendon at risk of tearing off the bone.

Another protective mechanism exists, therefore, to protect the tendons. This is the Golgi tendon organ reflex.

The Golgi organs detect and monitor the degree of force exerted against the tendon by a contracting muscle. If the force is too great, the Golgi organs fire off inhibitory signals via interneurons of the CNS which stops the transmission of motor signals and therefore stops muscle contraction.

This is an important reflex to be aware of, especially if working with clients who are lifting weights near their maximum capacity. If for example, a client is bench pressing over their limits it is possible that the Golgi tendon reflex will suddenly activate to inhibit muscle contraction, causing the bar to be dropped.

**Reciprocal inhibition**
During exercise, when one muscle or group of muscles contract (the agonists), the opposing muscle or group of muscles (the antagonists) relax. This is called reciprocal inhibition. The motor neural mechanisms which control reciprocal inhibition are vital for allowing the stretch reflex response.

During high intensity exercise, neural pathways for reciprocal inhibition can be disrupted and an antagonist muscle may contract when it is supposed to relax. This may lead to muscle pull or tear.

To minimise the risk of injury of both the agonist and the antagonist muscle simultaneously contracting, the technique of reciprocal inhibition stretch is used. This technique is based on the principle that a muscle stretch is more effective if the muscle being stretched is relaxed. Reciprocal inhibition stretching methods, working both the agonist and antagonist muscle groups, induce lengthening and relaxing responses and therefore produce a more effective stretch.

**The autonomic nervous system**

Efferent nerves that are under control of the autonomic nervous system are divided into two types:

- sympathetic nerves
- parasympathetic nerves

Sympathetic nerves are responsible for increasing activity and play a vital role in the 'fight or flight' mechanism. They work by releasing a chemical known as a neurotransmitter from the nerve ending to bring about an associated response. For example during times of stress, such as exercise, the neurotransmitters adrenaline and noradrenaline (also known as epinephrine and norepinephrine) are released to bring about the following changes:

- increased heart rate
- increased breathing rate
- vasoconstriction of the arteries and arterioles to increase blood pressure
- increased mobilisation of energy stores

Parasympathetic nerves are responsible for decreasing activity and are more active during times of relaxation and calm. They work by releasing a neurotransmitter called acetylcholine that has the opposite effect to adrenaline and noradrenaline. it is also secreted by the motor nerves at the neuromuscular junction. The effects are as follows:

- decreased heart rate
- decreased breathing rate
- vasodilation of the arteries and arterioles to decrease blood pressure
- decrease in the mobilisations of energy stores

The sympathetic and parasympathetic nervous systems are constantly working together to help maintain homeostasis.

**Nerve impulses**

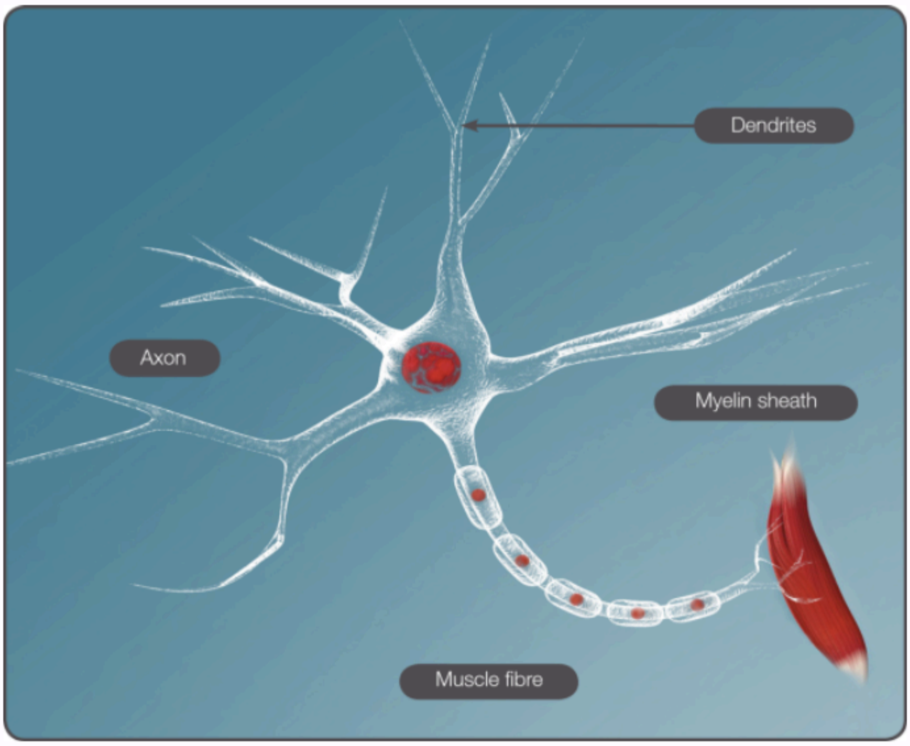
All messages, or impulses, that pass through the nervous system are transmitted by nerve cells. These nerve cells are called neurons. Neurons are the functional units of the nervous system and, essentially, the wiring system of the body. Each neuron is made up of a main cell body, dendrites and one axon. Extending from the main cell body are nerve fibres. These nerve fibres can be microscopic or up to one metre (3-4 ft) in length, and the longest fibres are those from the lumbar spine to the big toe. The cell body itself is responsible for directing information. Dendrites are responsible for transmitting impulses towards the cell body. The axon is responsible for transmitting impulses away from the cell body.

The conduction of information along nerves requires the involvement of neurotransmitter chemicals produced by the nerve cells that allow the nerve signal to 'jump' from one nerve to the next. These chemicals allow the brain to interpret signals from the periphery and to respond mechanically The are also extremely important in less obvious reactions, such as emotion desire blood pressure pain  and consciousness.

The two main types of neurons are:

1. **Motor neurons** - These transmit the impulse messages from the brain to the muscles and glands

2. **Sensory neurons** - These transmit the impulse messages from the sensory organs to the brain.




The nervous system is made up of a huge number of nerves cells or neurons. A neuron is an electrically excitable cell that processes and transmits information by electrical and chemical signalling.

Afferent (sensory) neurons - these are specialised cells that carry sensory stimuli from the external environment (eg, pain, pressure, light, taste, temperature) to the CNS. They typically have long dendrites and a short axon

Efferent (motor) neurons - these carry the motor commands from the CNS to the target cells (eg, muscles, glands, organs).

Each neuron consists of:

- a cell body - contains the nucleus, the nucleus contains the DNA of the cell and regulates cell activity

- many dendrites - tree-like extensions that receive information from other neurons and send those messages to the cell body
- an axon - an elongated fibre that transmits information AWAY from the cell body to the axon terminal
- Node of Ranvier - allows nutrients and waste products to enter/leave the cell, allows nerve impulses to move along the neuron through the process of depolarisation and repolarisation of the nerve membrane
- myelin sheath - fatty sheath that covers the axon, it acts as an insulator so that electrical messages can be sent quickly and easily
- axon terminals or synaptic terminals - these contain hundreds of sacs containing different chemicals called neurotransmitters.

**How do nerve impulses travel?**

When it is at rest, a neuron membrane is positively charged on the outside compared to the inside. This difference in charge is called the 'action potential'. The presence of an impulse causes the membrane to become permeable to sodium ions, which flood into the neuron through the sodium gate and depolarise it and alter its action potential. The flow of sodium ions then causes the neuron membrane to be more positively charged on the inside. Once the action potential threshold is reached, the impulse is allowed to travel along the neuron. When the action potential has peaked, potassium ions are forced out of the neuron through a potassium gate and the action potential is restored to resting state. The transport of sodium and potassium ions in and out of the neuron is known as the sodium potassium pump.

There is always more than one nerve or neuron involved in the transmission of a nervous impulse from its origin to its target destination. There is no physical contact between the nerves involved. The point at which a nervous impulse is transmitted across the gap (between one nerve cell and the next) is called the synapse.

**How do nerve impulses cross synapses?**

To cross the gap, the electrical impulse must be converted into chemical form. Vesicles containing neurotransmitters move into the synapse where they release their neurotransmitters. The electrical impulse is 'repackaged' in a form that can be carried across a gap (a bit like using a boat to cross water).

Receptor cells on the next neuron are also activated to receive and convert the chemical neurotransmitters to an electrical impulse so that it can continue on its way.

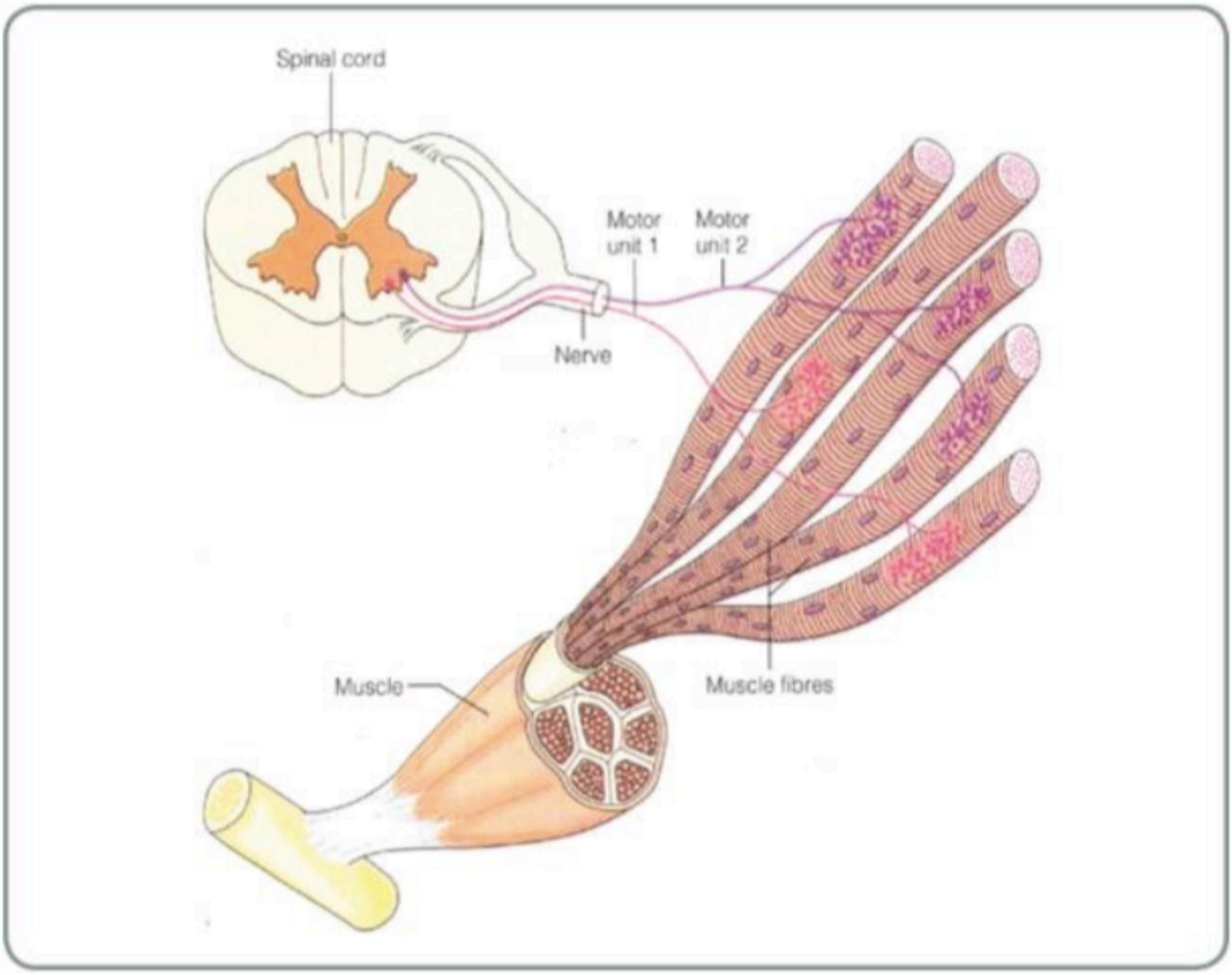
Two common neurotransmitters are:

- Acetylcholine
- Norepinephrine (noradrenaline)

**Connections between nerves and muscles**

A nerve that supplies a muscle is called a motor neuron and originates in the spinal cord. As it approaches a target muscle, the motor neuron separates into a number of branches. Each of these branches goes to an individual muscle fibre, ending at the neuromuscular junction.

A single motor neuron, plus all of the muscle cells it innervates, is called a motor unit.




Muscles are always in a slight state of tension, ready to react to a stimulus from their nerve supply. Without this 'tone', the body would collapse. When a nervous stimulus occurs, the muscle fibres work according to the 'all or none' principle. This means that muscle fibres do not partially contract; they contract fully or not at all.

Each muscle fibre is linked to the central nervous system by nerves. A motor unit consists of a single motor nerve (motor neuron) that connects to the muscle at the motor end plate. Therefore, all the muscle fibres in the motor unit receive stimulation from that motor nerve.

The strength of the muscle contraction will depend upon the number of muscle fibres brought into use. For example, to lift a light weight, a few muscle fibres within the muscle will contract to their maximum; the rest will remain inactive. To lift a heavier weight, more muscle fibres will be required. This process is called motor unit recruitment.

The muscle fibres in any given motor unit are distributed throughout the entire muscle, but only a few motor units need to be activated to bring about co-ordinated muscle contraction. This arrangement allows individual motor units to alternately switch on and off when work is performed.

The two key factors that affect the strength of a muscle contraction are the frequency of nerve impulses and the number of motor units activated. As the frequency of nerve impulses increases so too does the strength of the muscle contraction, and as the frequency of nerve impulses decreases, so the strength of the muscle contraction decreases.

One of the major adaptations to exercise training is improvement in the frequency of nerve impulses to muscles (neuromuscular pathways). Parallel to this is an increase in the number of motor units recruited; the more motor units activated by the central nervous system, the stronger the muscular contraction.

Nervous system responses are essential for life. As with any other system in the body, the nervous system can be improved with regular motor skill training, which results in the following adaptations:

- strengthening/growing new connections within the nervous system
- 
- speeding up the frequency of nerve impulses to motor units
- 
- improving synchronous recruitment of motor units, resulting in stronger muscle contraction.

**The 'all or none' law**

When a motor neuron reaches its firing threshold, every muscle cell in the motor unit it supplies will contract maximally. This is called the 'all or none' response. The force of a muscular contraction is dependent on:

- Whether the frequency of the stimulus in a motor neuron is high enough to bring about contraction in that motor unit. Fast twitch (FG) motor units have a much higher threshold than slow twitch (SO) motor units. They require a greater stimulus in order to be recruited. This threshold is sometimes referred to as the firing threshold.
- The number of motor units recruited. If a higher number of motor units are recruited, more muscle fibres are stimulated and a more forceful contraction occurs.

Muscles that require a large amount of precision in their movement, such as the muscles that move the eyes, will have lots of very small motor units, and only a few muscle fibres for each motor nerve. This will enable very fine movements with little force generation.

Muscles that require larger force development, for example the quadriceps, will have much larger motor units. One motor nerve will supply many muscle fibres so that more muscle fibres can be stimulated at once to create a more forceful contraction.

Exercise intensity will also determine the recruitment of motor units and therefore force development. Fast twitch (FG) motor units will require a large stimulus to be activated. This stimulus may be something like completing a maximal bench press lift or throwing a javelin. The stimulus required for activation of slow twitch (SO) motor units is much lower. Walking or cycling at a comfortable pace will be sufficient.

The recruitment order of motor units to bring about a coordinated contraction is dependent on the level of skill and experience of the individual.

As mentioned earlier in this section the nervous system can be 'hard wired' through regular training. If a movement pattern is repeated often enough, the pattern of recruitment becomes reflexive (needs little conscious input) and the body will recruit the muscles in the correct sequence to perform an exercise or activity correctly.

Consider the movement patterns required to carry out the butterfly swimming stroke. At first this will be a very clumsy and uncoordinated movement. With careful performance of a number of technique drills, an individual gradually learns the pattern of recruitment required and can carry out the stroke effectively with very little conscious input.

**Exercise and nervous system adaptations**

With regular activity the following adaptations can occur in the nervous system:

- strengthening of existing connections
- development of new connections
- increased speed and frequency of nerve impulses to stimulate stronger muscle contractions
- improved synchronisation of motor recruitment to achieve stronger muscular contractions
- better muscular coordination to improve application of force
- common movement patterns become automatic freeing up the mind for other tasks
- improved reaction time to a stimulus such as the starting pistol of a race
- improved balance due to improved efficiency of proprioceptors
- improved coordination due to improved motor recruitment patterns
- improved spatial awareness due to improved neural connections
- improved speed due to increased frequency and strength of nervous impulses
- improved agility due to improved speed and frequency of signal and neural connections.

**Special populations and the nervous system**

The nervous system is extremely complex. Unfortunately, this very complicated system can go wrong before, during and after birth. There are hundreds of disabling neurological diseases and disorders. These are very complex and therefore require specialist knowledge and care.

It is thought that ageing can bring about deterioration in the manufacture of the neurotransmitters, thereby interfering with nerve transmission. Additionally, ageing causes the internal architecture of the nerves to become deranged which affects the flow of chemicals through the nerve fibres. This results in a slower central processing time.

Some decline in nervous system function as we age can be attributed to poor blood supply (another ageing factor, mentioned earlier).

Increased risk of falls also can be attributed to the nervous system. The balance centre in the brain relies on information coming from the muscles. If any of this information is faulty or delayed, then balance may be affected.

## Key points for the nervous system

- The nervous system controls the actions of all bodily systems.
- The central nervous system (CNS), comprising the brain and spinal cord, has three main roles in the body: sensory, integrative and motor.
- The peripheral nervous system (PNS) consists of all other parts of the nervous system.
- The PNS is divided into two parts: the somatic (voluntary) and autonomic (involuntary) nervous systems.
- The autonomic system is further divided into the sympathetic system (the accelerator) and parasympathetic system (the brakes).
- Homeostasis ensures balance within the body, enabling it to operate effectively and efficiently.
- Nerve cells (neurons) transmit information to and from the brain by chemicals (neurotransmitters) that allow the brain to initiate the correct response.
- A motor unit consists of a motor nerve (neuron), motor end plate and all the muscle fibres contained within the unit. Muscles work on an all or none principle. The number of motor units activated and the frequency of the nerve impulses affect the strength of a muscle contraction.

**The Endocrine System**

The nervous system provides the body with a sensory system to react to the environment. However the body needs a slower method of maintaining homeostasis. This is the function of the endocrine system.

The endocrine system consists of a set of ductless glands that produce hormones.

If the CNS receives information from afferent nerves to show that the body is out of a homeostatic state, efferent nerves may send information to stimulate a response directly, or may send information to an endocrine gland to release a hormone. Once the hormone is released it travels to the target tissue to stimulate the appropriate response. The nervous system and the endocrine system work hand in hand, as one cannot function without the other.

Regulation of homeostasis is achieved through feedback loops. Feedback loops are either positive or negative.

**Negative feedback loops**
If blood sugar increases, this is sensed by the cells in the brain (feedback) which then triggers the release of hormones (in this case, insulin) to bring blood sugar back down.

Another example of this is when core temperature increases; this is sensed by thermoreceptors, which in turn trigger a sweating response to help bring the temperature back down. If core temperature falls, then the brain will invoke a shiver response to generate muscular heat and raise the temperature again.

**Positive feedback loops**
In contrast, a ‘positive feedback loop’ will cause levels to move even further away from normal. An example of this is the action of oestrogen during the menstrual cycle. Oestrogen released by the ovaries stimulates other endocrine glands to secret hormones that further increase levels of oestrogen.

**Endocrine glands and functions**

Hormones are released into the body from endocrine glands. There are many different endocrine glands in the body, but the main ones are identified below:

**Hypothalamus and pituitary gland**
The hypothalamus is situated at the base of the brain just above the pituitary gland, it is known as the master gland as it controls activity of the associated pituitary gland. As such it forms the link between the nervous system and the endocrine system.

The pituitary gland is situated at the base of the brain, just beneath the hypothalamus. The anterior part of the pituitary gland secretes growth hormone under the ultimate control of the hypothalamus. Growth hormone is a powerful anabolic hormone, important for tissue growth. Children and adolescents naturally have high levels of growth hormone compared to fully grown adults. Intense resistance training can stimulate a small increase in levels of growth hormone. The posterior part of the pituitary gland secretes a number of important hormones that control factors such as blood water content, lactation and so on.  The pituitary gland also secretes a range of different hormones known as 'trophic' hormones that act as messengers and controllers of the other endocrine glands.

**Adrenal glands**
The adrenal glands are situated on the kidneys, they secrete powerful hormones in response to stress, fear and excitement (sympathetic activity of the autonomic nervous system). The core of each adrenal gland is called the medulla, and this releases catecholamines - adrenaline and noradrenaline. These hormones act quickly and prepare the body for ‘fight or flight’ by increasing heart rate, breathing, muscle tone, alertness etc. Blood flow is directed to the working muscles and the digestive system is shut down whilst these hormones dominate. Fat is mobilised from adipose tissue, and glycogen is broken down to provide glucose fuel. Adrenaline and noradrenaline will normally be released just before and during intense exercise.

In more relaxed circumstances, levels of catecholamines fall, which restores blood flow to the digestive system, decreases heart rate and breathing rate and generally facilitates recovery (parasympathetic activity of the autonomic nervous system). This is sometimes referred to as ‘rest and digest’.

The outer layers of each adrenal gland are known as the cortex. Here corticosteroid hormones, such as cortisol, are made and released into the blood. A regular release of corticosteroid hormones is necessary for everyday function. However, levels rise under conditions of chronic stress. This can have several negative consequences including:

- reduced immune function
- catabolism (utilising muscle tissue for energy).

Chronic stress has many potential causes, such as a bereavement, worry about work, money, relationships, family problems, chronic pain from arthritic joints etc. Note that excessive exercising and extreme dieting can also be causes of chronic stress - factors to be aware of when dealing with clients.

The adrenal glands also produce small amounts of testosterone, regardless of gender. Hence women do have testosterone in their bodies - not just as much as men.

**Thyroid gland**
Situated in the neck and secretes thyroxine which stimulates metabolism in all cells of the body and plays a vital role in growth and development. Low levels of thyroxin can lead to retarded growth and development, reduced basal metabolism and rapid weight gain in adults. Low thyroid function is a condition that affects some people as they age and is relatively easy to diagnose with a blood test and treat with medication.

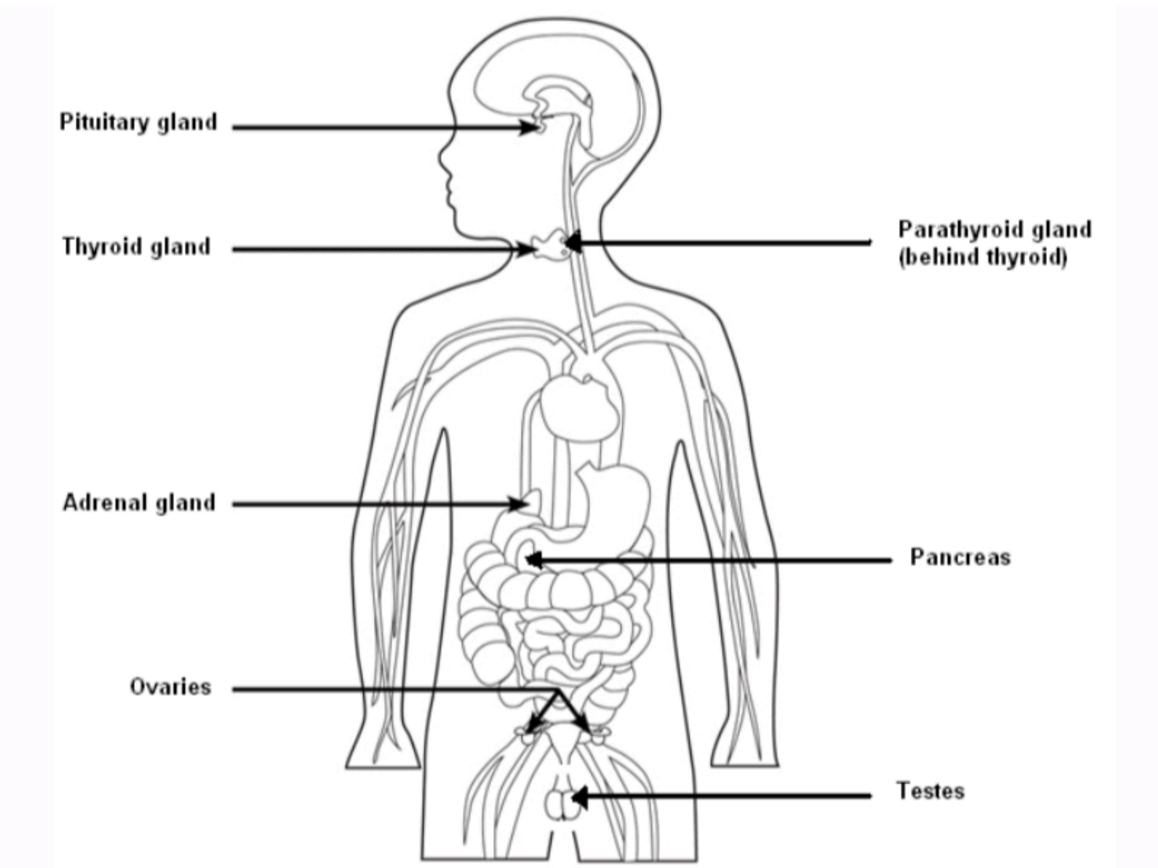
**Parathyroid gland**
The parathyroid glands are situated in the neck (behind the thyroid gland); humans usually have four parathyroid glands. They secrete parathyroid hormone (PTH), which regulates the levels of calcium in the blood - essential for muscle contraction and nerve impulse transmission. When blood calcium levels fall, PTH is released. This has the effect of increasing calcium absorption from the gut and also of breaking down bone in order to release calcium. Both these effects will serve to boost blood calcium levels again, but if there is insufficient calcium in the diet then this can be at the expense of bone mineral density.

**Pancreas**
The pancreas is situated near the stomach. it has a dual role; firstly as a digestive gland, producing enzymes that help to break down fats, carbohydrates and proteins, and secondly as an endocrine gland producing the hormones insulin and glucagon. Insulin is released into the blood in response to rising blood sugar levels (ie, after a meal). its action is to promote transport of blood sugar (glucose) into the cells to be used for energy or to be stored as glycogen. Thus insulin reduces blood sugar. In contrast, when blood sugar levels fall (ie, when someone has not eaten for several hours, or they have been exercising for a long time) then the hormone glucagon will break down stored glycogen to release glucose, thus increasing blood sugar levels.

So the two pancreatic hormones, insulin and glucagon, work antagonistically to keep blood sugar levels within a healthy range - a clear example of homeostasis.

**Ovaries (gonads)**
The ovaries are situated inside the female pelvic region, part of the female reproductive organs. As well as their role in producing an ovum each month as part of the menstrual cycle, they also have an endocrine function, secreting oestrogen and progesterone. This promotes the characteristics of femininity such as breasts, decreased body hair and increased body fat.

**Testes (gonads)**
The testes are situated outside the male pelvic region, involved in the reproductive system of the body - outside rather than inside to keep the cool enough for effective sperm production. As an endocrine gland, the testes secrete testosterone, a powerful anabolic hormone, which promotes the characteristics of masculinity, such as increased muscle size, increased body hair, decreased body fat and increased red blood cell count.



In general, hormones are much slower to create a response than nerves.

**Hormones**

- Hormones are substances released into the blood stream in small amounts.
- They produce a response which is distant from its site of production.
- They may stimulate the production of other hormones in other glands.
- Hormones are made from lipid (fat) or amino acid (protein).
- Hormones regulate and coordinate different organs of the body to maintain homeostasis.

There are two different types of hormones, steroid and peptide; the body has a different speed of response to each of these. While some hormones are catabolic, others are anabolic. Catabolic hormones break things down, while anabolic hormones build things up.

**Steroids**
Usually end in '-one' eg, testosterone. Steroids are slow acting, long lasting hormones that control themselves by means of feedback. When a hormone is oversupplied the gland will stop making it. When the level of hormone drops too low, the gland will begin secreting again, until the hormone level rises sufficiently.

**Peptides**
Peptides are made of protein. They are fast acting and short lived. Insulin is an example of a peptide.

### Hormone summary

| Gland | Location | Main hormone(s) | Actions |
|---|---|---|---|
| Hypothalamus and pituitary | Base of brain | Growth hormone | • Increases fat metabolism<br>• Increases glycogen synthesis<br>• Increases blood glucose levels<br>• Promotes growth in children and young adults<br>• Promotes muscle mass |
| Adrenals | Top of the kidneys | Adrenaline and noradrenaline (catecholamines) | • Facilitates sympathetic nervous system activity |
| | | Corticosteroids | • Regulates stress and immune responses<br>• Control of carbohydrates, fats and protein metabolism |
| Thyroid | Neck | Thyroxine | • Increases fat metabolism<br>• Increases glycogen synthesis<br>• Increases blood glucose levels<br>• Promotes growth in children and young adults<br>• Promotes muscle mass |
| Parathyroid | Neck (behind the thyroid) | Parathyroid hormone | • Controls levels of blood calcium to maintain muscle contraction and nerve impulse transmission |
| Pancreas | Abdominal cavity close to stomach | Insulin and glucagon | • Control blood sugar levels |
| Ovaries | Pelvic region | Oestrogen and progesterone | • Promote feminisation |
| Testes | Pelvic region | Testosterone | • Promote masculinisation |