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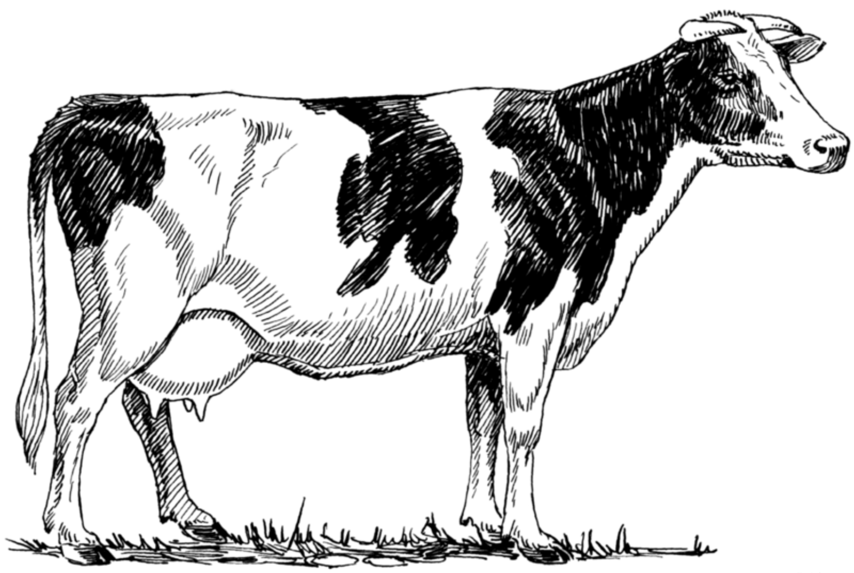
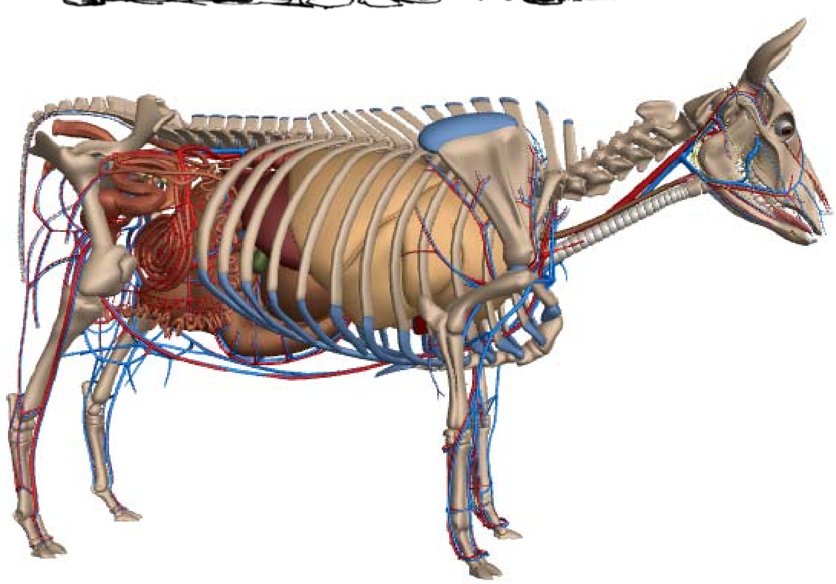
Unit Standard 18

Demonstrate knowledge of animal anatomy and physiology

Version 6 Level 3 Credit 4





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Learning objectives

Profitable livestock farming in New Zealand relies on the ability of farmers to maintain their livestock in a healthy and productive condition. To do this it is helps to have some understanding of how an animal's body works.

This module will introduce you to the basic principles of anatomy and physiology of farm livestock, in particular cattle, sheep, horses and pigs.

When you have finished this module you will be able to:

- Identify and describe the major structural body parts of animals
- Identify the internal organs and organ systems of animals
- Describe the primary functions of these organs and organ systems
- Describe and compare ruminant and non-ruminant digestive systems and their processes

Introduction

This learning module deals with the anatomy and physiology of farm animals.

What is anatomy and physiology?

Anatomy is a branch of science which describes the bodily structure of animals and other organisms and the relationships between their individual parts, i.e. the main structures and organs and how they fit together.

Physiology, on the other hand, deals with how the individual organs and structures work.

For example, anatomy describes the parts that make up an animal's circulatory system system such as the heart, arteries, veins and capillaries, but physiology goes into the detail of how these individual parts work so that the entire circulatory system works properly.

Why is this knowledge useful to farmers?

Knowing about the parts of the body and how they work in a normal healthy animal is useful because it helps you recognise signs and symptoms which might indicate that something is not right. This may help you to decide if and when you need to treat an animal, as well as what what you need to do to remedy the situation. It may also help you to decide if you are able to treat the signs and symptoms yourself or need to call in a veterinarian or other expert.

Anatomy and physiology is studied at many levels in all types of organisms including animals, birds, plants, bacteria and fungi. At the largest level gross anatomy studies organs and organ systems mainly by eye and by dissection of carcasses. At the smallest level anatomy and physiology is studied at the cellular level using microscopes and biochemistry.

In this module we will look at the gross anatomy and physiology of the main structural and internal organs and organ systems of large animals commonly farmed in New Zealand, i.e. cattle, sheep, deer, horses and pigs:

- Skeleton, muscles and tendons
- Skin
- Circulatory system, heart and blood vessels
- Respiratory system, lungs and airways
- Reproductive systems of males and females
- Excretory system, kidneys and bladder
- Nervous system, brain, spinal cord and nerves
- Digestive system of ruminant and non-ruminants

Supporting information:

To help you with your understanding of anatomy and physiology of animals it is strongly recommended that you also take the opportunity to look at the flowing books that are available through the Telford Library:

McCracken, T., Kainer, R., Spurgeon, T., & Brooks, G. (1999). *Spurgeon's Color Atlas of Large Animal Anatomy. The Essentials*. United Kingdom: Blackwell Publishers.

Raynor, M. (2005). *The Horse Anatomy Workbook : A Learning Aid for Students Based on Peter Goody's Classic Work, Horse Anatomy*. London, United Kingdom: Robert Hale Ltd.

Brega, J. (2005). *Essential Equine Studies: Bk. 1 : Anatomy & Physiology*. London, United Kingdom: Robert Hale Ltd.

If you are interested, there are also many useful resources on the internet which may help you understand anatomy and physiology in more detail than presented in this learning module.

Structural anatomy and physiology

The first section of this module deals with the structural anatomy and physiology of animals. As its name suggests this is the anatomy and physiology of the main body parts which make up the structure of the animal rather than the individual internal organs. Structural anatomy will cover:

- skeleton
- muscles
- tendons
- skin

The structural anatomy and physiology of all mammals, including agricultural livestock is similar in terms of the number of components, their general shape and their arrangement in the body.

The Skeleton

The skeleton of a mammal such as a cow (illustrated) is made up of rigid bones which are connected together by muscles, tendons, ligaments and cartilage.

Together they create an internal framework that forms the supporting structure of an animal, holding it upright, giving it shape and strength and allowing it to move.

The skeleton has several functions:

- It protects delicate soft organs in the body. For example, the bones of the skull (cranium) protect the brain, the vertebrae (bones of the spinal column) protect the spinal cord, and the rib cage protects the heart and lungs.
- It serves as a framework on which muscles, tendons and ligaments are attached, which provides the animal with the ability to move (i.e. locomotion).
- Bones in the skeleton, or more specifically the marrow found inside the bones, are the site of red and white blood cell production.
- Bones also provide storage for the minerals calcium and phosphorus, both of which are essential for healthy metabolism (i.e. the biochemical functions which support life).

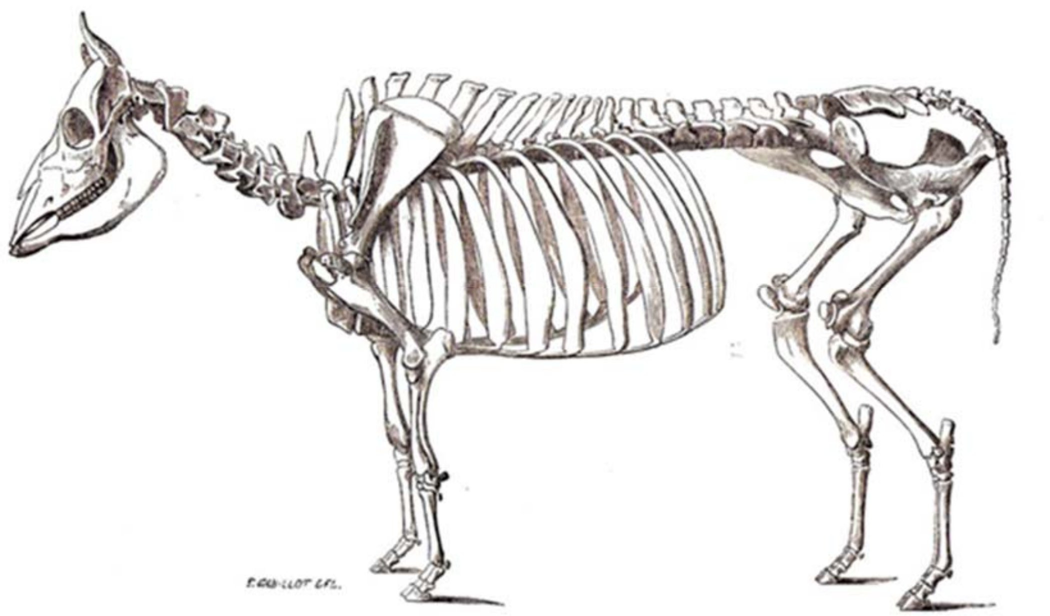

Figure 1 Skeleton of a cow

Image by Meyer, 2011. Licenced by CC0 1.0

Bone types

There are four main types of bone in a mammal skeleton (refer to the cow skeleton image above):

1. **Long bones** – the long bones of the upper and lower limbs and feet. These are strong dense bones designed to support the animal's weight and provide movement (locomotion).
2. **Short bones** – the bones of the 'wrist' and 'ankles'. These are designed to allow movement of the larger limb bones (articulation).
3. **Flat bones** – the ribs, shoulder blades, pelvis and skull. These are designed mainly for support and protection of internal organs. The shoulder blades and pelvis also provide large areas for muscle attachments for limbs.
4. **Irregular bones** – the vertebrae (spinal column) and facial bones. These are also designed for support and protection.

Bone structure

Bones are largely made up of two types of tissue:

1. **Compact bone** is very dense (but not solid), and has a texture similar to ivory. It is made up of cylinders or tubes of mineral crystals and protein fibres. The large weight bearing bones such as limb bones are mainly compact bone which can withstand the large stresses they are subjected to every day.
2. **Spongy bone** is found as the inside layer of compact bone. Despite its name, it is not soft and spongy, but actually a very strong honeycomb texture: it is arranged along points of pressure or stress making bones both strong and light. Spongy bone also usually contains red bone marrow.

Bone shape and the amount of compact and spongy bone vary between bones. In general, the long limb bones are similar to the structure in the diagram above. They consist of a hard hollow shaft of compact bone with spongy bone at each end. The hollow shaft contains yellow marrow, and the spongy bone red marrow.

The shorter short, flat and irregular bones are generally made of a "sandwich" of spongy bone covered with a layer of compact bone, with red bone marrow being found within the spongy bone. A hollow core containing yellow marrow is not present. A rib bone is typical of this type.

The diagram below shows the internal structure of bone tissue. Don't worry about the scientific names!

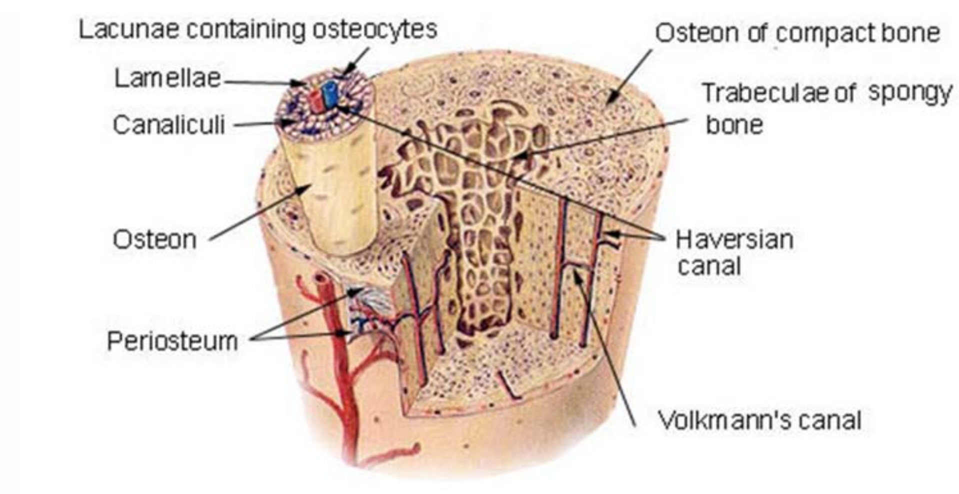

Figure 2 Structure of the bone

Notice how the bone is made up of a honeycomb-like lattice fed by blood vessels and nerves. The lattice is made up of a scaffold of collagen fibres (strong protein fibres) stiffened with hard minerals (calcium and phosphorus salts). The protein/mineral scaffold is what makes bones hard and strong. The gaps in the scaffolding are filled with living cells (called osteocytes), blood vessels and nerves. The blood vessels supply nutrients and remove wastes to the living bone tissues.

In the diagram, the periosteum is a thin tough membrane which covers the surface of the bone. It contains cells, blood vessels and nerves and is responsible for growth of the bone. It is also the tissue which repairs broken bones.

Bone marrow

Bone marrow is a soft tissue found in the cavities of bones. It is the place where new blood cells are produced. There are two types of bone marrow: red marrow and yellow marrow. Red marrow is found mainly in the spongy parts of flat bones such as hip bone, breast bone, skull, ribs, vertebrae and shoulder blades, and in the spongy bone at material at the ends of the long leg bones. Yellow marrow is found in the hollow shafts of the long limb bones (e.g. leg bones).

Red blood cells, platelets and most white blood cells develop in red marrow. Some white blood cells also develop in yellow marrow. Red blood cells are responsible for transporting oxygen around the body. Platelets are involved in blood clotting. White blood cells are important in an animal's immunity and defences against disease.

The colour of yellow marrow is due to a large number of fat cells. In cases of severe blood loss, the body can quickly convert yellow marrow into to red marrow to rapidly increase blood cell production.

Muscles

Muscle is a soft tissue found in most animals. Muscle cells contain fibres that slide past one another, producing a contraction that changes both the length and the shape of the cell. Muscles function to produce force and motion. They are primarily responsible for maintaining and changing posture, locomotion, as well as movement of internal organs, such as the contraction of the heart and the movement of food through the digestive system.

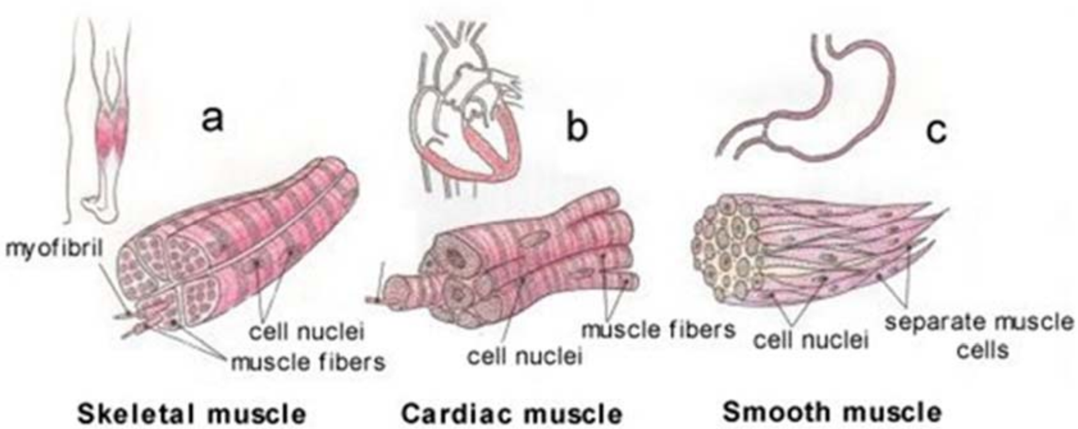

Figure 3 Types of muscle fibres in animals

Retrieved from https://peanutboard.wordpress.com/2012/09/29/comparison-of-skeletal-muscle-smooth-muscle-and-cardiac-muscle/

Muscle tissue is made up of cells that are specialised for contraction. There are three types of muscle found in animals:

Skeletal muscle

Skeletal muscle is anchored by tendons to bone and is responsible for most of an animal's voluntary movements and in maintaining posture. Most of what we call meat is skeletal muscle. It is also known as 'striated' muscle because under a microscope the muscle cells have characteristic 'striations' (stripes) across their cells. Skeletal muscles are normally under an animal's voluntary control, i.e. the animal can move them at will.

There are also two types of skeletal muscle fibres:

1. Slow twitch or red muscle has a rich blood supply and is specialised for long term activity without fatigue. Slow twitch muscle fibres are good for endurance activities like maintaining body posture or walking. They can work for a long time without getting tired.
2. Fast twitch muscle fibres are specialised for short bursts of high energy activity. Fast twitch muscles are good for rapid movements like jumping or galloping. They contract quickly, but get tired quickly, as they consume lots of energy.

Most muscles are made up of a mixture of both slow and fast twitch muscle fibres. For example, leg muscles and muscles along the spine ("eye fillet") which are involved in maintaining posture contain mainly slow twitch muscle fibres. In contrast, muscles that move the eyes are made up of fast twitch muscle fibres. Muscles with a lot of fast twitch fibres are paler than those with a lot of slow fibres because has a more limited blood supply.

The red and white meats of a chicken are a good example of slow and fast twitch skeletal muscles which are easy to see. Dark meat, like in chicken legs, is mainly made up of slow twitch fibres. White meat, like in chicken wings and breasts, is largely made up of fast twitch muscle fibres. Chickens use their legs for walking and standing, which they do most of the time. This doesn't use much energy. They use their wings for brief bursts of flight. This requires lots of energy and the muscles involved tire very quickly.

Smooth muscle

Smooth muscle is found in the walls of the digestive tract, blood vessels and other internal organs. It is also known as visceral muscle. Smooth muscle is usually responsible for most of the involuntary movements of internal organs e.g. contractions of and movement of materials through the digestive system, urinary and reproductive systems and changes in the diameter of blood vessels (e.g. to control blood pressure). It is not normally under and animal's voluntary control, i.e. the animal has no conscious control over these muscles.

Cardiac muscle

Cardiac muscle or heart muscle is a special muscle type which makes up the heart. It is striated like skeletal muscle but unlike the skeletal muscle it is adapted to be resistant to fatigue and it is not under the animal's voluntary control. A special characteristic of cardiac muscle cells is that they contract under their own built-in rhythms without any external stimulation (heart-beat).

Tendons and ligaments

A tendon (also known as sinew) is a fibrous connective tissue which attaches muscle to bone. Tendons may also attach muscles to structures such as the eyeball. A tendon is made up of dense and incredibly strong fibrous connective tissue with the fibres all running along the length of the tendon, rather like a rope. Its purpose is to transmit the strong mechanical force of muscle contraction to the bones. The tendon is firmly connected to muscle fibres at one end and to components of the bone at its other end.

A ligament is a fibrous connective tissue similar to tendon but which attaches bone to bone. Ligaments hold joint structures together and keep them stable whilst allowing them to move. For example ligaments hold the bones together across the shoulder, hip and knee but they are flexible and elastic (like a bungy cord) to allow the joints to move.

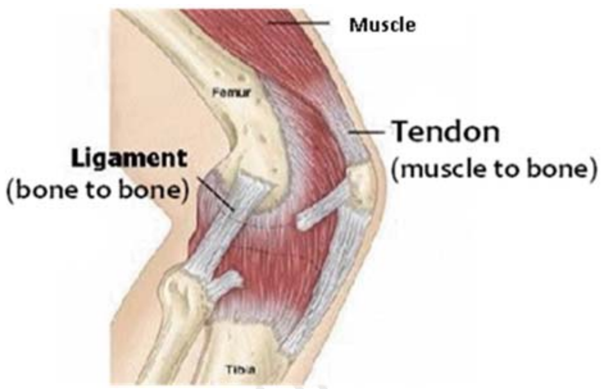

Figure 4 Tendons and ligaments in a knee joint

Retrieved from http://solidlifefitness.com/wp-content/uploads/2014/03/english-vocabulary-tendon-ligament.jpg

In tendonitis the tissue of the tendon or its connection with the muscle or bone becomes inflamed. This causes pain and discourages the animal from moving the muscle and the bones it is attached to. Tendonitis is a common cause of lameness.

Occasionally a tendon or ligament can be 'torn'. This usually means the tendon has been pulled away (disconnected) from the bone. Therefore the muscle will no longer be attached to the bone. In human athletes the Achilles tendon connecting the calf muscle to the heel can sometimes become torn. The person is then unable to walk. Similarly athletes can tear ligaments which normally hold the knee joint straight. When this happens the knee joint can bend sideways (as it shouldn't!).

Cartilage

Cartilage is a stiff but flexible connective tissue found in many areas in the bodies of animals. These include the joints between bones, the rib cage, the ear, the nose, the elbow, the knee, the ankle, the bronchial tubes (see below) and the intervertebral discs. It is not as hard and rigid as bone but is stiffer and less flexible than muscle. The cartilage in joints such as, shoulder, hip and knee joints is called articular cartilage and it provides a smooth surface for the bones to slide over each other when they move.

Cartilage is composed of specialized cells which produce a large amount of a stiff gel-like substance containing tough collagen fibres and flexible elastic fibres. Cartilage does not contain blood vessels. The cells in cartilage rely in nutrients and oxygen diffusing through it. Therefore cartilage grows more slowly than other tissues and when it is damaged it takes longer to repair. Osteoarthritis is caused by damage to articular cartilage in moveable joints so that the bones rub on each other when they move, causing pain.

Skin

The skin is the outer covering of living tissue of an animal. It is part of the integumentary system which includes hair, scales, feathers, hooves, and nails. It made up of layers of specialised tissues and guards the underlying muscles, bones, ligaments and other internal organs.

Function of the skin

The skin of animals has many functions:

1. **Protection**. Skin is barrier to pathogens (disease causing organisms) and the tough skin layers (hide) provides physical protection to internal organs from outside threats such as cuts and abrasions, aggression from other animals etc. Pigments in the skin and fur can also help protect the skin from ultra-violet light in sunlight.
2. **Sensation**. Skin contains a variety of nerve endings that react to heat and cold, touch, pressure, vibration, and tissue injury (e.g. pain).
3. **Regulation of body temperature.** Sweat glands and dilated (expanded) blood vessels in the skin help an animal to lose heat, while constricted vessels greatly reduce blood flow under the skin and conserve heat. Animals can also adjust the angle of hair shafts rotrap or exclude air in the fur to change the amount of insulation provided.
4. **Control of water loss:** the skin provides a relatively dry and semi-permeable barrier to fluid loss from the internal organs.
5. **Water resistance.** Skin also acts as a water resistant barrier. Oils and grease from skin glands help to waterproof the animal’s fur and hide from the outside (like a raincoat), so essential nutrients aren't washed out of the body.
6. **Storage**. Skin acts as a storage depot for fat. This is a store of nutrients for the animal and also can help with heat loss (insulation). Pigs, cattle and sheep often have varying amounts of subcutaneous fat which influences the quality of the meat to consumers.
7. **Absorption**. Though skin normally acts as a barrier from the outside, animals can absorb chemicals through the skin. This is important in farming because ‘pour-on’ chemicals are often used to control insect and parasite pests.
8. **Excretion**. The glands in skin can also be a route of excretion of some waste products (e.g. salt and urea).
9. **Vitamin D**: Most animals produce vitamin D in the skin under the influence of sunlight on the skin. The amount produced varies according to the amount of ‘bare’ or hairless skin exposed to sunlight. Vitamin D is important for bone growth
10. **Communication**. The colour of skin and hair can be used by animals to communicate though this is rare in farm animals. However hormonal scent chemicals (pheromones) excreted in skin and other glands can spread onto the skin and fur to attract a mate (e.g. the ‘ram’ smell and the billy-goat smell).

11. **Milk production.** Milk glands in the udder are actually modified (by evolution) sweat glands and so are part of the skin.

Structure of skin

The diagram below shows a cross section through a section of skin.

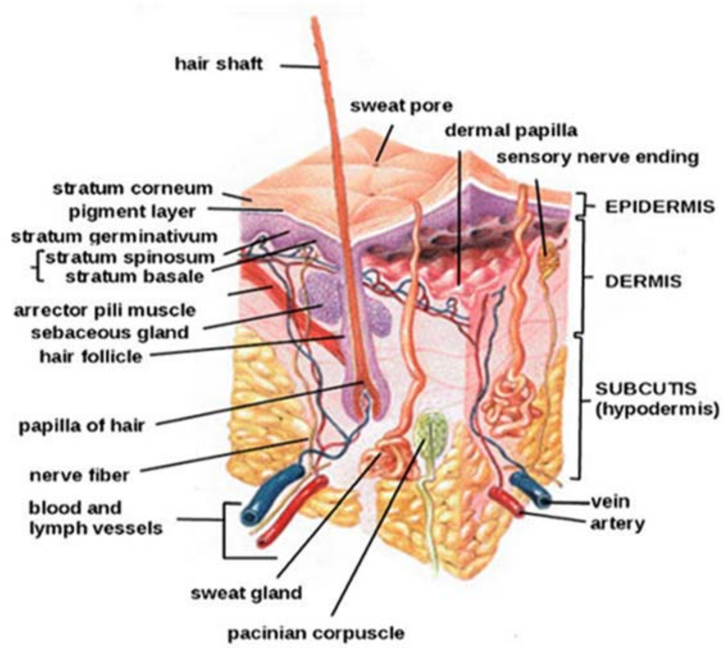

Figure 5 Cross section of the skin

Retrieved from https://www.boundless.com/physiology/textbooks/boundless-anatomy-and-physiology-textbook/the-integumentary-system-5/functions-of-the-integumentary-system-66/protection-401-7368/images/human-skin/.

The skin is made up of two main layers called the epidermis and the dermis.

Epidermis. This is the tough outermost layer of the skin. It gets its toughness from a protein called keratin. The epidermis is also made up of layers. The top layer is called the stratum corneum and is made up of dead, mature skin cells. These cells are const **pressure receptor** by cells from the lower layers of the epidermis. The layer below is called the stratum germinativum. The cells of this layer continuously divide and form new cells to replace the ones that are constantly shed. It is also the layer where keratin is formed, and pigment may also be formed here which gives skin its colour. As the cells divide and grow they gradually flatten out as they move up to surface and harden. This process takes between 15 and 30 days, depending on the area of the body.

Dermis. This lower layer of the skin contains collagen and elastic fibres that give strength to the skin. This layer also contains the blood vessels, hairs and nerves. Structures in the dermis include:

- **Hair:** Hair (or wool) is made up of keratin which grows out of hair follicles embedded in the dermis. The shape of the follicle determines whether hair is curly or straight. Arrector pili muscles connect the hair follicle to the skin and are responsible for raising and lowering the hairs for temperature control or display – e.g. 'getting hackles up'.

- **Sebaceous glands:** These glands are connected to the hair follicles. They produce sebum, which is an oily substance that helps keeps the hair flexible. Sebum is the main 'oil' in greasy wool.
- **Sweat glands:** Sweat glands are coiled tubular glands found in most of the skin. They produce a watery secretion mainly involved in cooling skin (sweating).
- **Sensory Nerves:** These include nerves sensitive to heat, cold, pressure and pain. When these nerves are not functioning properly they can produce sensations such as numbness, pins-and-needles, pain, tingling, or burning.
- **Blood Vessels:** These structures carry vital nutrients and oxygen-rich blood to the cells that make up the layers of skin and then carry away waste products.

Together the epidermis and dermis form the cutaneous (skin) layer. The subcutaneous layer (area below the skin) lies underneath the cutaneous layer and is sometimes called the hypodermis or superficial fascia. The hypodermis holds most of the body's fat, so it varies in thickness from one animal to another.

Creases form over joints because the skin always folds the same way as the joints bend. The skin is usually thinner in those areas and is firmly attached to the underlying structures by connective tissue. The dermis is the portion of skin which becomes leather after tanning 'cures' the tough collagen and protein fibres in the dermis.

Test Yourself #1

The answers to the following are all in the notes, but try to answer the questions without looking back at your notes to test how much you have learned.

True or False?

1. The bones that make up the skeleton of an animal are dead material.

2. Tendons anchor muscles to bones, allowing the animal to move by bending the skeleton at joints.

3. Muscle cells are specialised for contraction.

4. Skin provides protection against damage by ultra violet light (sun burn) and also provides camouflage for an animal.

5. Tendons are made of elastic, yellow coloured tissue.

6. The skin does not receive stimuli such as pain, heat and cold from the environment, therefore an animal cannot feel what is happening in its environment.

7. Red and White blood cells are produced in the bone marrow.

8. Cardiac muscle is responsible for most voluntary muscle movement in an animal.

Internal anatomy and physiology

The next section of this module deals with the internal anatomy and physiology of animals. This will deal with the internal organ systems and their individual organs. As with structural anatomy and physiology, these are very similar in most mammals. The exception, which is very relevant to farm livestock, is the digestive system which has some special adaptations depending on the main food type of animals (e.g. in ruminants and non-ruminants). We will look at these later. The organ systems and organs we will be looking at are:

- Circulatory system, heart, blood vessels, lymphatic system and lymph nodes
- Respiratory system, lungs and airways
- Reproductive systems of males and females
- Excretory system, kidneys and bladder
- Nervous system, brain, spinal cord and nerves
- Digestive system of ruminant and non-ruminants, including the main differences between their digestive processes.

The circulatory System

The circulatory system refers to the organs and tissues which are responsible for transporting materials throughout the entire body. The circulatory system transports nutrients (such as glucose, amino acids and electrolytes), water, and oxygen to all the body's cells and carries away wastes such as carbon dioxide and urea which the cells produce as they metabolise and perform their own functions. It also carries hormones which communicate between different parts of the body, and distributes blood cells (e.g. white blood cells) which help to fight disease.

The main part of the circulatory system is the cardiovascular system comprising the heart (cardio-) and the arteries, veins and capillaries (-vascular) which transport blood around the body. However there is another important part called the lymphatic system, which drains recycled blood plasma (lymph) which filters out of the blood vessels and into the spaces between the individual cells. Lymph nodes are an important part of the lymphatic system (see later).

Together the cardiovascular system and the lymphatic system make up the circulatory system.

The main components of the circulatory system are:

1. The cardiovascular system:
   a) Heart
   b) Arteries
   c) Capillaries
   d) Veins

2. The lymphatic system
   a) Lymph vessels
   b) Lymph nodes

The cardiovascular system

The diagram below shows the cardiovascular system of an animal (a horse). It shows the general layout of the main components; the heart, arteries, and veins. It does not show the capillaries, which lie between the ends of the arteries and the veins (discussed below).

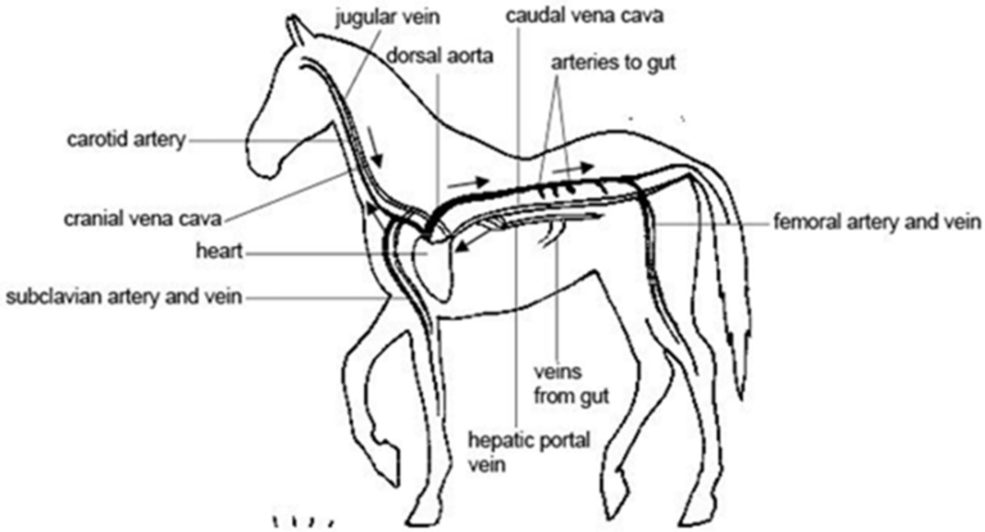

Figure 6 the cardiovascular system of the horse

In summary, the cardiovascular system is a system of blood vessels through which blood is pumped by the heart. The heart pumps blood along arteries to the lungs and extremities of the body through arteries. The arteries leaving the heart have a large diameter and strong walls to withstand the high pumping pressure. As the blood flows away from the heart the arteries branch and become smaller in diameter until they reach the tissues where they turn into fine capillaries. The capillaries branch through the tissues and it is here that the nutrients and oxygen leave the blood and enter the cells and waste products and carbon dioxide leave the cells to be carried away by veins. As the blood travels back towards the heart the veins merge together to form larger veins until they become the large veins which bring the blood into the heart again for recirculation.

The diagram on the next page shows a diagrammatic representation of cardiovascular system, showing the heart, arteries, veins and capillaries and the direction of blood flow. Note that left and right seem to be the wrong way round! This is a quirk of anatomical terminology. The convention is that we refer to left and right from the point of view of the "body". So if you imagine the animal is facing you (head on), the diagram refers to the animal's left and right.

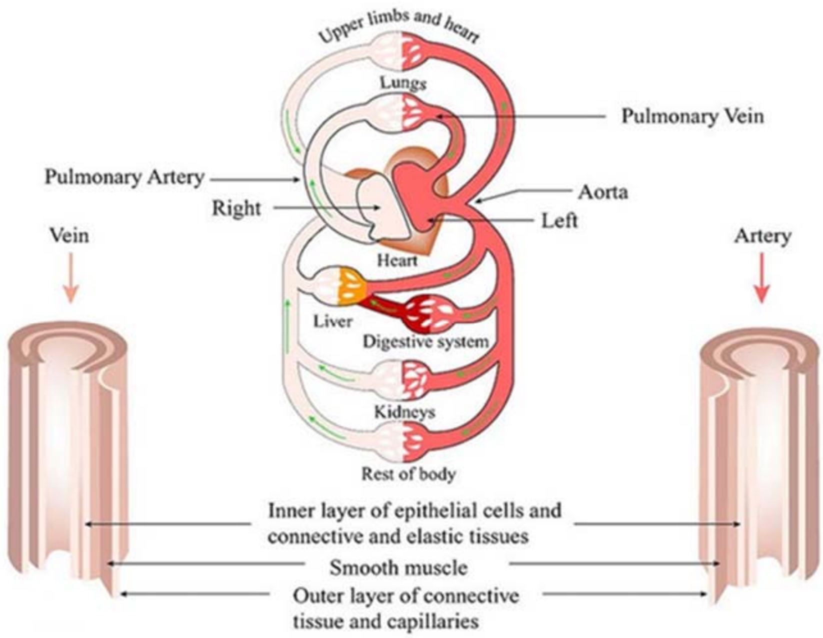

Figure 7 Cardiovascular system

Image by MIT OpenCourseWare, 2007. Licenced under CC BY-NC-SA 2.0

The heart

The heart is the pump that keeps the blood flowing around the body.

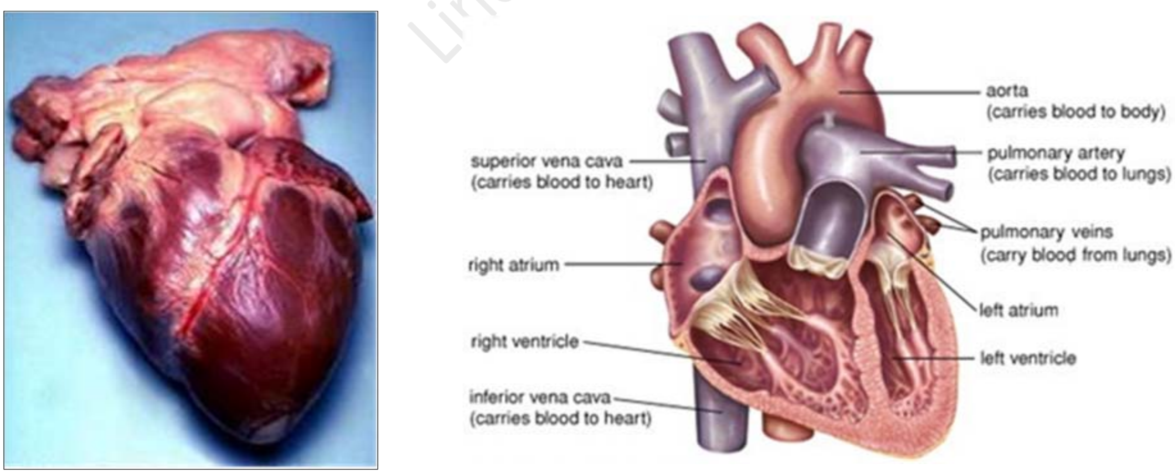

Figure 8 The Heart

Image on left retrieved from http://funmozar.com/real-human-heart/

Image on right retrieved from http://www.britannica.com/science/heart

In most mammals the heart lies ventral (lying towards the abdomen or belly) in the thorax (chest cavity) with its apex or point quite close to the diaphragm. In some species it may be displaced towards the left side, although the point may be slightly to the right. The picture above shows the external appearance of a heart. Note the coronary artery and vein which can be seen on the surface of the heart – these supply blood to the muscles that make up the heart tissue.

The heart wall is made up of cardiac muscle known as myocardium. As noted earlier, cardiac muscle is adapted to be resistant to fatigue and it is not under the animal's voluntary control. A special characteristic of cardiac muscle cells is that they contract under their own built-in rhythms without any external stimulation (heart-beat). This is sometimes known as spontaneous contraction.

The heart is covered on the outside by a tough membrane known as the pericardium and beneath that a thinner, smooth membrane known as the epicardium. Between these two membranes there is a thin layer of slippery pericardial fluid which acts as a lubricant and helps to reduce the friction caused by the heartbeat. (Normally the amount of pericardial fluid is very small, but in animals suffering from certain diseases, the amount of fluid increases greatly and this can damage the heart). On the inside surface, the heart is lined with a thin, smooth membrane called the endocardium.

The picture on the previous page shows the internal structure of the heart. The heart has four chambers. Two little chambers on the top called the right atrium and left atrium (plural = atria) which accept blood from the veins returning to the heart. They pump venous blood into the big chambers below, called the right and left ventricles. These big muscular chambers then pump blood out into the arteries which take the blood out to the organs.

The valves between the heart chambers, and the valves between the chambers and the big veins and arteries which enter and leave the heart, makes sure that blood flow is in one direction only.

A short animation (3 minutes) showing this process can be found on YouTube at http://www.youtube.com/watch?v=oE8tGkP5_tc (accessed October 2013). You may be able to search for it using the, search terms "the circulatory system davejaymanriquez"

Double circulation of the blood

The cardiovascular system is actually a "double circulation" system with separate parts: the pulmonary circulation (lungs) and the systemic circulation (the rest of the body) so that the blood travels through the heart twice for every complete circuit of the body. The sequence is:

1. Blood from the veins enters the right side of the heart from where it is pumped to the lungs.
2. In the lungs the blood picks up oxygen from the lung's air sacs and releases carbon dioxide. This is discussed further in the section on the respiratory system.
3. Oxygenated (red) blood then travels back to the left side of the heart where the oxygenated blood is pumped round the rest of the body to the capillaries.
4. In the capillaries oxygen is released into the tissues and carbon dioxide picked up.
5. The deoxygenated blood returns to the right side of the heart via the veins and the cycle repeats itself.

The distance through the pulmonary circulatory system to the lungs is quite short compared to the systemic circulation. So the muscle mass of the right side of the heart (pumping to the lungs) is smaller than the left side (pumping to the rest of the body. This is why the two sides of the heart are different sizes – the left side of the heart has to pump harder than the right.

The diagram below shows the double circulation of the blood through the heart showing the how the blood from one side of the heart goes to and from the lungs (pulmonary circulation) and the other side to and from the body (peripheral circulation).

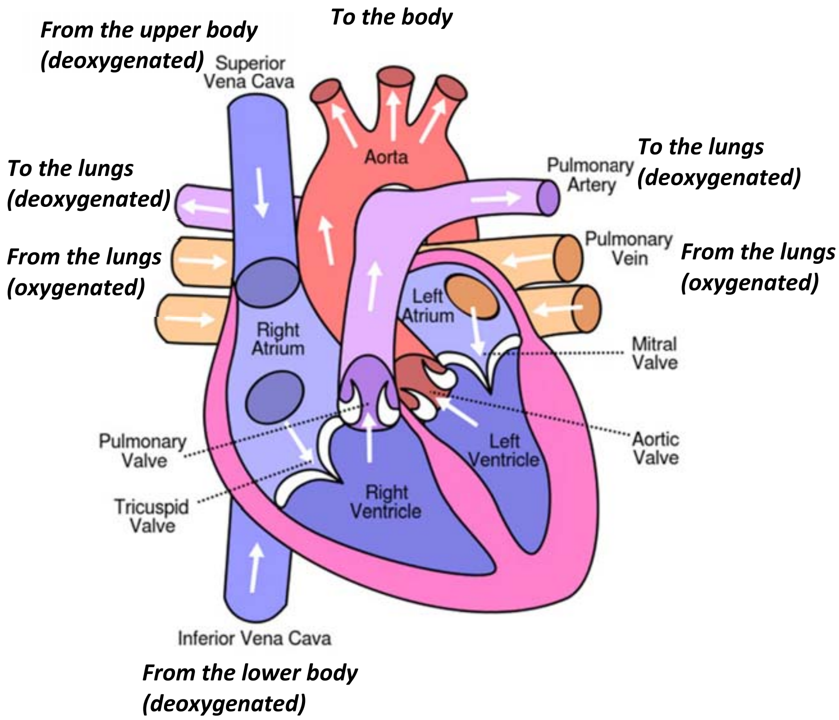

Figure 9 The double circulation of the heart

Blood vessels

The blood vessels are the arteries, capillaries and veins.

Arteries are blood vessels that carry blood away from the heart towards the lungs, body or the tissues. The walls of arteries are thick, with wide layers of fibrous and elastic tissue because they have to withstand high pressure as the heart pumps. As the blood flows away from the heart the arteries divide into smaller arteries called arterioles. These divide further until they become capillaries. Note that the pulmonary artery carries deoxygenated blood to the lungs and the aorta (the big artery leaving the right side of the heart) carries oxygenated blood to the body.

Tip: **Arteries Always** carry blood **Away** from the heart

Capillaries are the smallest blood vessels or tubes that carry blood through the tissues. They have very thin walls which allow small molecules to pass through from the capillary to tissues or from the tissues back into the capillary. The networks of capillaries that penetrate throughout the tissues are known as capillary beds. The **capillary beds** are where oxygen, carbon dioxide, nutrients and waste products are exchanged with the tissues. After passing through the tissues, capillaries merge to form venules which in turn join together to form veins.

Veins are blood vessels that carry blood from tissues back towards the heart. The walls of veins have the same elastic and fibrous layers as arteries, but are much thinner. The blood carried in veins is at much lower pressure than in the arteries so the walls of veins are usually much thinner. Veins also contain one-way valves, especially in the limbs, to help prevent back-flow of blood in the veins and to ensure that the blood move back towards the heart.

Blood

Blood the fluid which carries oxygen, carbon dioxide, nutrients, waste products and hormones around the body. The main components of the blood are:

1. **Red blood cells.** Red blood cells are responsible mainly for carrying oxygen from the lungs to the body's tissues. They are red because of the pigment haemoglobin which is the chemical compound in the cell to which the oxygen molecule is attached. When haemoglobin is carrying oxygen to the tissues (oxygenated blood) it is bright red. When deoxygenated (after giving up oxygen to the tissues) haemoglobin becomes a dark bluish red colour. Red blood cells may also carry carbon dioxide attached to the haemoglobin.
2. **White blood cells.** White blood cells are important in an animal's defence against pathogens (disease causing organisms) and foreign materials in the body. There are several types of white blood cells, each with specialised functions. Some white blood cells are involved in recognising and producing antibodies against bacteria and viruses and other foreign materials (e.g. pollen). Some white blood cells engulf and digest bacteria and foreign matter. White blood cells may gather at the site of infection as part of the animal's response to infection. This can cause swelling which may result in an abscess containing pus. Pus is a mixture of dead bacteria white blood cells and other cellular materials.
3. **Platelets.** Platelets are specialised blood cells involved in blood clotting that help stop bleeding from damaged blood vessels. When a blood vessel is damaged and begins to leak out, platelets start to stick to the damaged area. As they stick together they attract more platelets, fibres and other blood cells to help form a plug to seal the broken blood vessel. When the platelet plug is completely formed (a scab) the wound stops bleeding.
4. **Plasma.** Plasma is the yellowish transparent liquid part of the blood. The plasma carries the blood cells and other components throughout the body. Chemicals dissolved in the plasma include hormones, carbon dioxide, glucose, proteins and other nutrients and waste products.

The lymphatic system

The lymphatic system is a special network of lymphatic vessels, ducts and lymph nodes which are involved in fluid regulation, fat absorption and immunity.

The lymphatic system is made up of a network of lymphatic vessels that link together with all of the internal organs and connect to the cardiovascular system near the heart. The lymphatic system carries a clear fluid called lymph. Lymph is the fluid which filters out from the capillaries in tissues as the blood is pumped through under pressure (a bit like a garden soak-hose). Lymph is basically recycled blood plasma – the blood cells remain in the capillaries. The main function of the lymph system is to drain this fluid from the tissues and return it to the blood system so that tissues do no become 'waterlogged'. If the lymphatic system fails to drain fluid form the tissues it can result in swelling, technically known as oedema (pronounced "eedeema") but also known as 'dropsy'.

Lymphatic capillaries are interwoven with the blood capillaries. Fluid and proteins are forced out of the arterial end of the blood capillary and into the spaces between the individual cells (also known as the interstitial space). Lymph is drained back to the blood system through a separate set of tubes, called the lymphatic system.

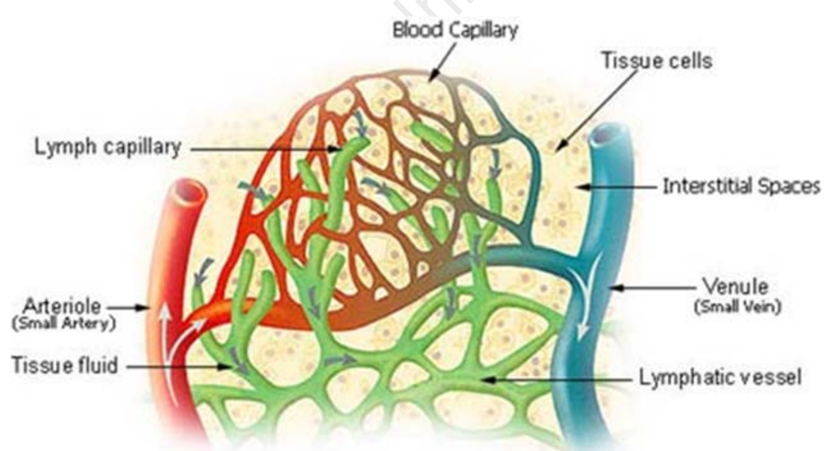

Figure 10 Vessel of the lymphatic system

Image retrieved from https://en.wikipedia.org/wiki/Lymphatic_system#/media/File:Illu_lymph_capillary.jpg.

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The lymphatic vessels are similar to veins, with thin walls and valves to prevent backflow. The lymph in the lymphatic system is not 'pumped' by the heart. Instead the lymph flows back to the heart due to pressure on the vessels as skeletal muscles and surrounding tissues move and change shape. Once in the lymphatic capillaries, the lymph moves into progressively larger vessels, passes through the lymph nodes and/or spleen, reaches the large ducts, and drains into the blood circulation at the large veins in the upper chest near to the heart. Thus, the fluid is eventually returned to the blood, which helps maintain the proper balance of fluid between the blood vessels and the tissues.

Near the small intestine, where fats are digested and absorbed, the lymphatic vessels have a special role in the absorption of digested fat from the small intestine.

Lymph nodes

The lymphatic system also has an important role in immunity via lymph nodes. Lymph nodes are round or bean-shaped structures that are widely distributed throughout the body. They are embedded in connective tissue or fat and are concentrated in the groin, armpits and neck (under the jaw) regions. They are typically about 2cm in length, depending on the size of the animal. The lymph nodes filter the lymph before returning it to the veins. They are arranged so that all lymph has to pass through at least one node before returning to the veins. The lymph nodes filter out disease causing organism or other foreign proteins (called antigens) and can launch an immune response to them if necessary. Lymph nodes contain lots of visible nodules which are packed with special white blood cells responsible for immunity.

When an animal becomes infected the nodules become very active and can become enlarged as the immune system tries to fight the disease. In fact swollen lymph nodes can be used as aclinical indicator of disease. Humans with tonsillitis often have swollen lymph nodes in the neck. Possums infected with bovine TB may have swollen lymph nodes in the armpit region. Cancers may also cause inflammation of the lymph nodes.

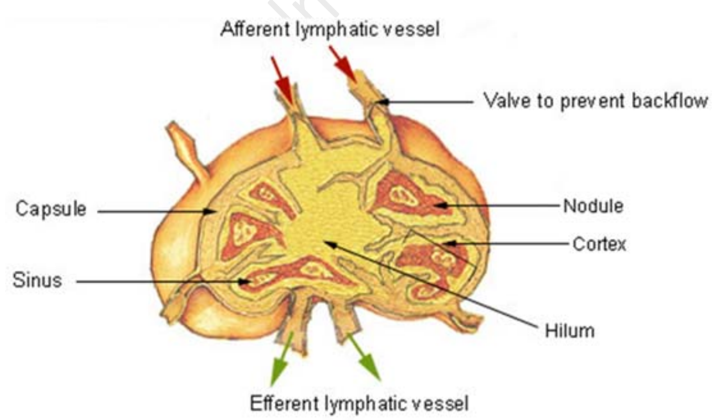

Figure 11 Lymph node structure

Image retrieved from
https://en.wikipedia.org/wiki/Lymph_node#/media/File:Illu_lymph_node_structure.png.
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To view some photos of a feral pigs lymp node infected with bovine tuberculosis (TB) please go to:

http://www.tbfree.org.nz/identifying-bovine-tb.aspx

The Respiratory System

The respiratory system is the system of organs and tissues that are responsible for exchanging gases with the circulatory system, particularly oxygen and carbon dioxide.

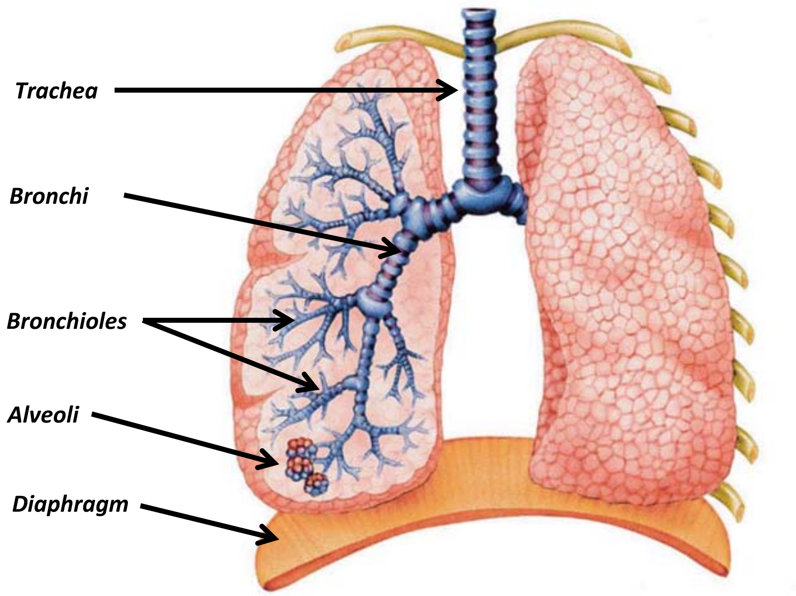

Figure 12 Structure of the respiratory system

Image retrieved from http://nametsomathiba.blogspot.co.nz/2011/05/gene-therapy-cures-color-blind-monkeys_2200.html

The main anatomical features of the respiratory system are the airways, lungs and respiratory muscles.

Airways

The airways are the tubes which connect the lungs with the outside air. These are the pharynx, larynx, trachea and bronchi.

The **pharynx** is the technical term for the mouth, nose and throat cavities. The pharynx is a common passageway for both the respiratory and digestive systems. Both food and air can pass through the pharynx.

The **larynx** is a structure at the junction of the airways (the trachea) and the digestive system (oesophagus). It acts as a valve to that prevents food and water entering the airways (choking). The larynx is also modified for producing sound - the voice box.

The **trachea** (windpipe) is the single large tube which descends down the animal's neck to where it branches into two bronchi. The bronchi divide further as they pass into the lungs to form **bronchioles**. The dividing structure of the trachea, bronchi and bronchioles is sometimes called the **bronchial tree**. A characteristic of the bronchial tree is that all the tubes are strengthened by rings of cartilage which provide strength and keep the airways open. The tubes of the bronchial tree are lined with mucus producing cells equipped with tiny hairs (or cilia) which continually sweep upwards towards the larynx. These cilia continually sweep the mucus and any foreign material (dust, pollen, smoke, etc.) up towards the larynx from where it can be coughed up and expelled from the lungs and airways.

The lungs

The lungs are located in the thoracic (chest) cavity and are protected by the rib cage. Along with the lungs the thoracic cavity also contains the heart and is separated from the abdominal cavity by the diaphragm. The heart sits between and below the two halves of the lungs.

The lung tissue is made up a sponge-like tissue consisting of a mass of microscopic air sacs calls alveoli. These alveoli sit at the ends of the smallest bronchioles on the bronchial tree (like clusters of grapes).

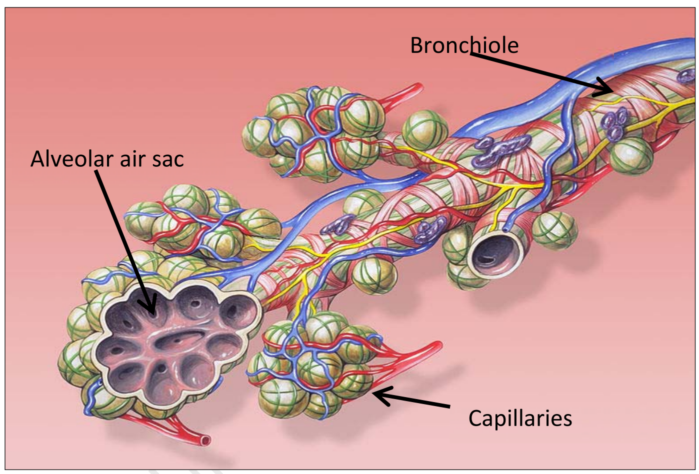

Figure 13 Structure of the lung

The alveolar sacs are where the gas exchange takes place between the air and the blood capillaries surrounding the air spaces. This is where oxygen inhaled from the air is absorbed by the blood flowing in the capillaries and carbon dioxide is released from the blood to be exhaled.

The lung is air-tight. It is contained in an air-tight membrane called the pleural sac. The alveolar spaces in the lung and the total lung structure are kept inflated by the negative pressure (suction) in the thoracic cavity. If either the lung or the thoracic cavity is punctured the lungs will collapse and the animal will not be able to breathe and will die. Lungs may become punctured (or leaky) in severe cases of lung infection which may damage the pleural sac. Though rare, the thoracic cavity may be punctured from the outside in an accident; e.g. punctured by a cow horn or a horse running into a fence.

Respiratory muscles

When the animal is at rest the **diaphragm** is the main muscle involved in respiration (breathing). It is a thin sheet of muscle which separates the thoracic (chest) and abdominal cavities. Normally the diaphragm is concave (dome shaped) curved upwards into the thoracic cavity. During inspiration (breathing in) the diaphragm contracts and as it flattens it increases the volume of the chest, allowing the lungs to expand and fill with air. During exhalation (breathing out) the diaphragm relaxes and the elasticity of the lungs makes them collapse pulling up the diaphragm which returns to its resting dome shape. This reduces the volume of the chest cavity and air is forced out of the lungs.

During activity when oxygen demand is high, the muscles attached between the ribs in the chest wall (the intercostal muscles) also assist with breathing. During inspiration these muscles lift the ribs forwards and outwards to further increase the volume of the thorax during inspiration. During expiration these muscles relax and ribs move down and inwards reducing the volume of the chest cavity.

he diagram below shows how the contraction of the muscular diaphragm casues air to be taken into the lungs, and relaxation of the diaphragm pushes air out of the lungs, allowing the animal to breath. As the diaphragm contracts and becomes flatter, this increases the volume of the thorax, creating a negative pressure inside the chest cavity, causing the lungs to expand and air to be drawn in.

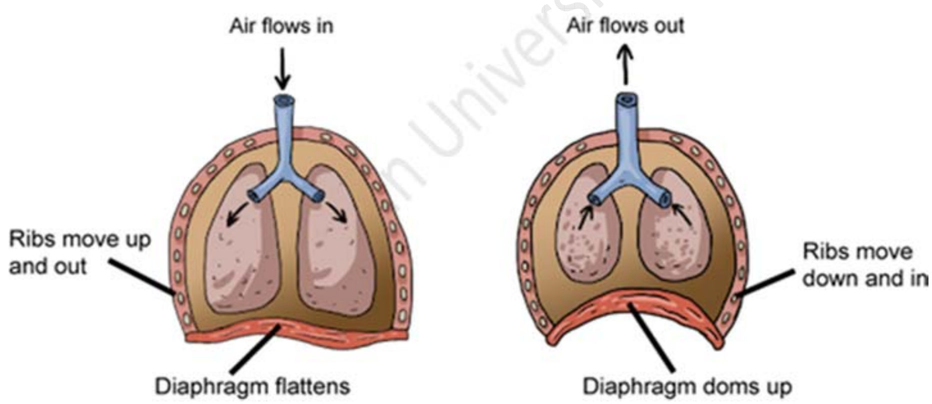

Figure 14 The breathing cycle

Image retrieved from http://www.shmoop.com/animal-movement/animal-respiration.html

During inspiration air travels through the pharynx and larynx, then along the trachea, bronchi and bronchioles to finally reach the alveoli, where gas exchange takes place. When air is expired, it travels from the alveoli, along the bronchioles and bronchi to the trachea and through the larynx and pharynx to the outside environment. To see the respiratory system of the horse, showing the placement of the trachea, bronchus, bronchioles, lungs and diaphragm as describe on the previous page, please go to this link.

The Nervous System

The nervous system is the part of an animal's body that coordinates the voluntary and involuntary actions of the animal and transmits signals between different parts of its body. It consists of two main parts, the **central nervous system** (CNS) and the **peripheral nervous system** (PNS).

The CNS consists of the brain (the main nervous 'control system') and spinal cord (the main nerve 'trunk cable') running down the inside the bones of the spinal column (i.e. vertebral column).

The PNS consists mainly of nerves, which are long fibres that connect the CNS to every other part of the body via sensory and motor nerves (also referred to as neurons) and the autonomic nervous system.

Sensory nerves relay sensory information about touch, pain, heat etc. They also provide the brain with information about the relative positions of parts of the skeleton (e.g. the limbs). Motor neurons, communicate between the CNS and the muscles to control voluntary movement (e.g. skeletal muscles, muscles of the eye). The nerves of the autonomic nervous system control and regulate involuntary functions such as breathing, movement of the digestive and reproductive organs and reflexes such as coughing and sneezing. Animals cannot normally control these functions voluntarily.

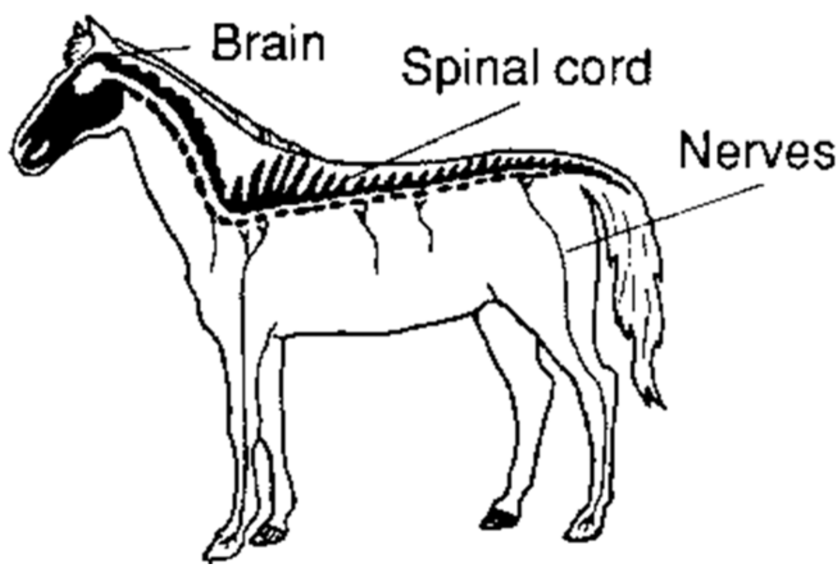

Figure 15 The nervous system of a horse

Image retrieved from http://becuo.com/organ-system-of-animals

The nervous system is made up of specialised nerve cells known as neurons. These are cells that are able to conduct electrical impulses. The function of these neurons is to receive and co-ordinate information about the external environment and from tissues and organs of the body and then react according to the information received. Nerve impulses are then carried throughout the body (via the nervous system) to stimulate whatever movement, activity or behaviour may be required in response to the information received.

The tissue of the nervous system is made up of two types of cells:

1. neurons or nerve cells which can conduct electrical impulses
2. connective tissue that runs between the nerve cells

The diagram below shows a nerve cell or neuron.

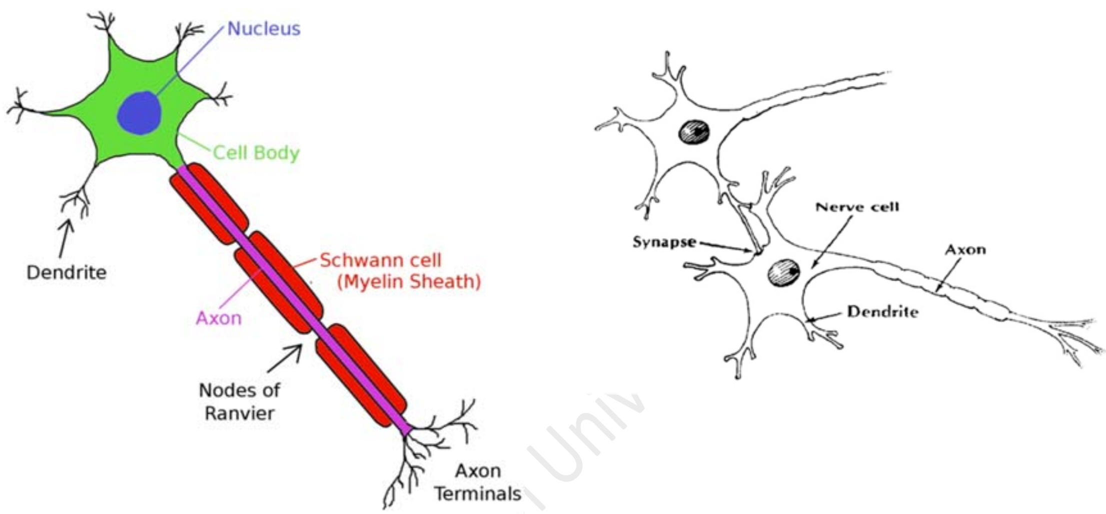

Figure 16 Nerve Cell or neuron

Image on left retrieved from http://www.quickiwiki.com/en/Action_potential. Licenced under CC BY-SA 3.0

Image on right retrieved from http://www.psypost.org/2014/01/scientists-offer-new-insight-into-neuron-changes-brought-about-by-aging-22265

A typical nerve cell or neuron consists of:

- A cell body with a nucleus and several dendrites (which look like spines).
- An axon, along which the nerve impulse travels. Axons can vary in length from less than 1mm to several cm).
- Most nerves are surrounded by a fatty myelin sheath which is produced by Schwann cells. This acts as electrical insulation between adjacent nerve fibres.
- Nerve endings (axon terminal), which are found at the end of the axon.

'Nerves' usually consist of bundles of neurons lying together. Each neuron is insulated from its neighbour by its myelin sheath and the bundle is surrounded by connective tissue – similar to a domestic electrical cord (i.e. three insulated wires in a sheath). In the nerves the axons are arranged end to end with the axon terminal of one neuron connected to the dendrite of the next like a daisy-chain. The electrical impulses in the neurons travel from the terminal of one axon to the dendrite of the next cell through special junctions called synapses.

The Brain

The brain is a specialised part of the nervous system, composed almost entirely of nervous tissue (neurons). In higher mammals the surface of the brain is much folded, producing many curved grooves which give the surface of the brain a convoluted appearance. This folding increases the surface area of the brain without increasing the volume, allowing a large increase in the number of brain cells contained in the structure. The picture shows a side view of a sheep's brain.

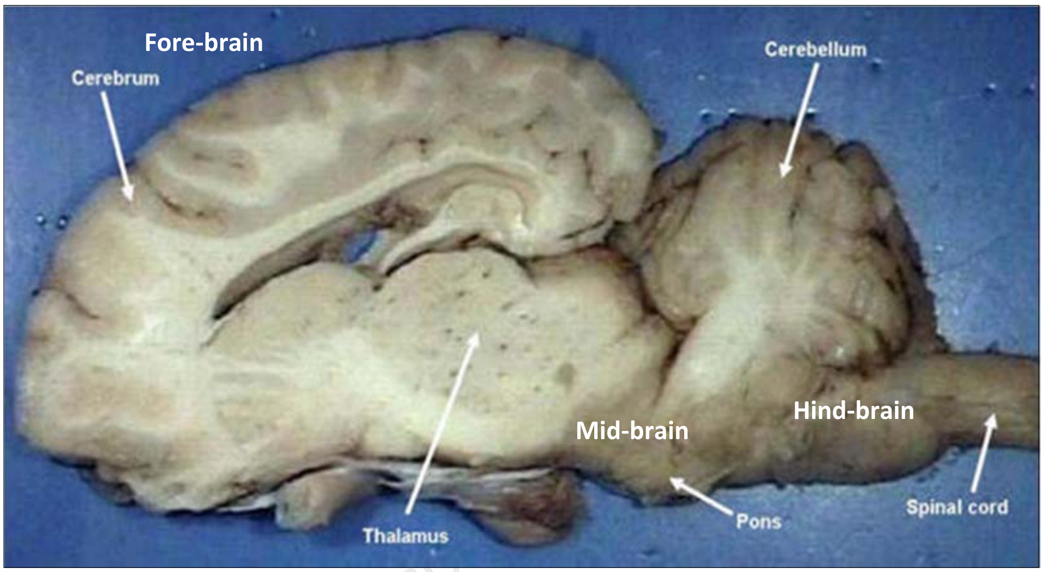

Figure 17 Side view of a sheep's brain

Image retrieved by http://neuropracticumstudyguide.weebly.com/lateral-sagittal.html

The brain (and spinal cord) is made up of two different types of tissue: grey matter (mainly cell bodies and nuclei) and white matter (mainly long, fibrous, conducting parts of nerve cells).

The brain has three main parts:

1. The fore brain (cerebrum) or cerebral hemispheres
2. The mid brain
3. The hind brain

The **forebrain** is responsible for a variety of functions including receiving and processing sensory information, perceiving, and controlling motor function (movement). It is the 'thinking' part of the brain. Underneath he forebrain is are the thalamus and hypothalamus which are responsible for functions such as motor control, relaying sensory information, and controlling autonomic functions. Most of the actual information processing in the brain takes place in the cerebral cortex.

The **midbrain** is the part that connects the hindbrain and the forebrain. This region of the brain is involved in auditory (hearing) and visual responses as well as motor function. The optic (eye) and auditory (ear) nerves connect into this area of the brain.

The **hindbrain** extends into the spinal cord and contains structures such as the pons and cerebellum. These regions assists in maintaining balance, coordination of movement and automatic functions as breathing, heart rate, and digestion.

The spinal cord

The spinal cord is the main trunk connection of nerves from the brain to the rest of the body. It consists of a thick bundle of nerves which passes down a hollow passageway inside the bones of the vertebral column all the way through the pelvis and tail bones. At each joint in the spinal column nerves emerge on either side between the individual vertebrae. These nerves then connect with the organs and tissues in that particular region of the body. For instance the nerves that control the shoulders and rib cage emerge near the head-end of the spinal column. Those responsible for the legs and tail emerge from between vertebrae nearer the tail end of the spinal column.

Damage to the spinal column can affect nervous impulses travelling beyond the point of damage. If the nerve in the spinal column becomes pinched or severed the muscles and sensory nerves beyond the break (towards the tail-end) cannot communicate with the brain. This results in muscular paralysis and loss of sensation beyond the site of nerve damage.

The Reproductive System

The reproductive system is the system of organs and tissues which work together to allow animals to reproduce, create offspring and continue the species. In mammals the major organs of the reproductive system include:

- the external genitalia (**penis** and **vulva**)
- the **testes** and **ovaries** (also known as ***gonads***) which produce reproductive cells, (***sperm*** and ***eggs*** – also known as ***gametes***)
- the accessory organs, glands and tissues which are designed to help bring the eggs and sperm together for fertilisation during and after mating
- the uterus and associated tissues which protect and nourish the foetus until it is born

As with the other organ systems of mammals the reproductive systems are similar in all species. However, unlike the other organ systems they are different in males and females. In biological terms they are ***sexually differentiated***, with different organs with different function in males and females.

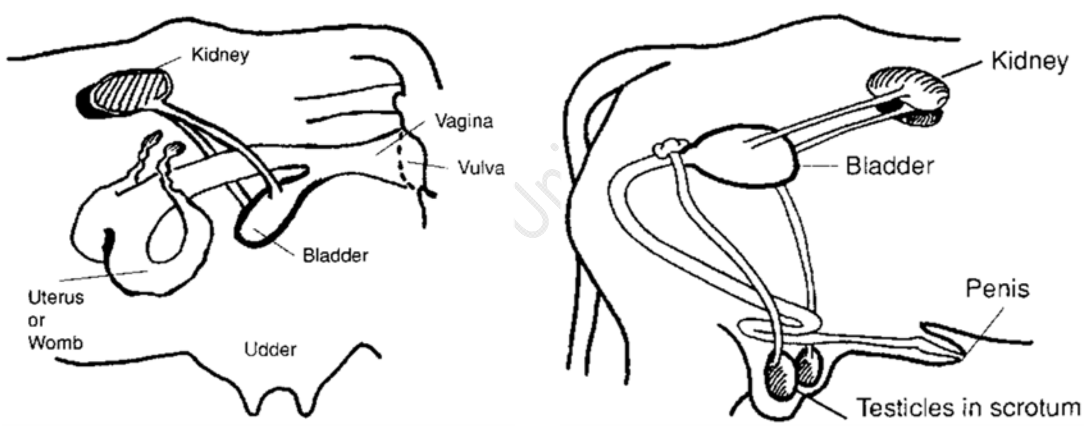

Figure 18 Reproductive system of a cow (left and a bull (right)

Images retrieved from http://www.fao.org/docrep/t0690e/t0690e04.htm

In farm livestock, sheep, cattle, horses and pigs, male reproductive systems are similar and female reproductive systems are similar except for slight variations in the size, positions and shapes of the organs depending on the species. These are noted below where appropriate.

The female reproductive system

This diagram below shows the reproductive system of the cow in more detail.

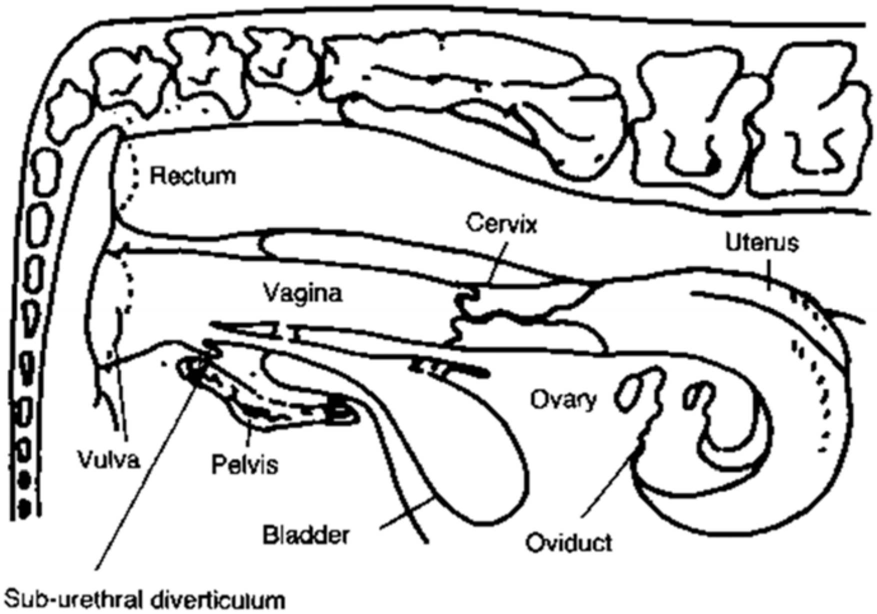

Figure 19 Reproductive organs of a cow

Image retrieved from http://www.fao.org/wairdocs/ilri/x5442e/x5442e04.htm

The function of each component is the same in females of all species. The main organs of relevance here are:

- Ovaries
- Fallopian tube (uterine tube)
- Uterus
- Cervix
- Vagina
- Vulva

The **ovaries** are the primary sex organs of a female animal. In most mammals the ovaries lie ventral (towards the belly) to the kidneys and are supported, along with the uterus, in a band of connective tissue.

The ovaries are the source of eggs (oocytes). Eggs are single cells with a nucleus which contain half the genetic material required for the fertilised embryo (the other half is provided by the male's sperm). Eggs are released seasonally during the oestrus cycle after the animal has reached puberty. Females have two ovaries and at birth each ovary contains a very large number of immature eggs, some of which will mature and be released during each successive oestrus cycle. The hormones oestrogen and progesterone, which help to regulate the reproductive cycle, are also produced in and released from the ovaries. Ovulation is when an egg is released from the ovary.

The **fallopian tubes** (also known as the uterine tube), are the fine tubes with a funnel shaped opening at the end of each uterine horn. During ovulation, the ovary expels eggs, some of which are caught by the funnel of the fallopian tube. The fallopian tube carries the eggs towards the uterus where they may be fertilised after mating. After successful mating the egg is may be fertilised by a sperm in the upper reaches of the fallopian tube (near to the ovary), after which the fertilised egg is moved along the tube into the uterus.

The **uterus** is a hollow muscular organ in which the foetus develops and from which it is delivered during birth at the end of pregnancy. The uterus is basically 'Y' shaped with the two arms of the Y (known as the uterine horns) leading into the fallopian tubes and the base of the Y to the cervix and vagina. The uterus is fairly small in nonpregnant animals, but is capable of considerable expansion to accommodate the growing offspring. In a nonpregnant cow, the uterus is less than 5cm long, but it is capable of enormous expansion, to accommodate the growing calf, which can weigh up to approximately 40kg.

The size and position of the uterus varies with the animal species, particularly the length of the uterine horns. This depends on the number of young in a "litter":

- In pigs the uterus has two long horns and a very short body. Pigs usually give birth to a large number of young compared to sheep and cattle.
- In cattle and sheep the uterine horns are shorter and the body longer than in pigs. Cattle normally bear one calf and sheep single or twin lambs. Also, the uterine horns of a cow are coiled 'downwards' so that the ovaries actually lie underneath the uterus.
- In horses the uterine body is large and the uterine horns are very small in relation to sheep, cattle and horses.

When an egg is released into the fallopian tube, hormonal changes in the female cause the lining of the uterus (the endometrium) to change. This allows implantation of the fertilised embryo, development of the placenta and growth of the foetus.

The walls of the uterus are very muscular (smooth muscle – described earlier). These muscles expel the foetus from uterus at birth.

The **cervix** is the neck of the womb. Its function is to protect the internal environment of the uterus from contamination. The cervix has a thick wall made up of cartilage and muscle which makes the structure rigid. The cervical canal is sealed throughout most of the oestrus cycle, but it relaxes slightly during oestrus to allow the passage of sperm into the uterus and fallopian tubes. During pregnancy the cervix is completely sealed by a thick plug of mucus. For most of the time the cervix is only a few centimetres in diameter but during the birth of the young animal the cervix is able to expand enormously (for example, to allow the passage of a calf that may be 40cm in diameter).

The **vagina** is the female organ of copulation. It is the site where the male deposits semen during mating. It is also the canal along which the foetus will travel during the birth process.

The **vulva** is the external opening of the female reproductive tract. It's purpose is to act as a seal to prevent the accidental entry of foreign material into the reproductive tract.

The male reproductive system

This diagram below shows the reproductive system of a bull in more detail.

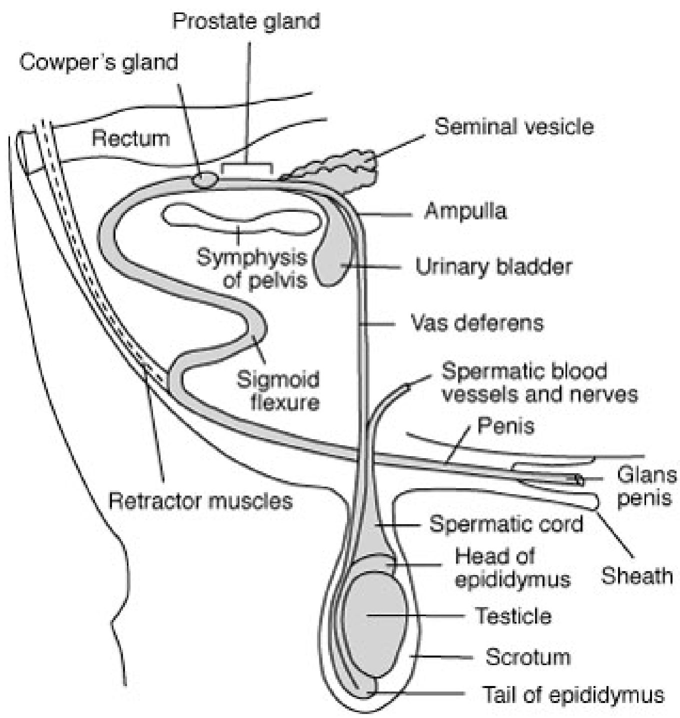

Figure 20 Reproductive organs of a bull

Image retrieved from http://extension.missouri.edu/p/G2016

The function of each component is the same in males of all species. The main organs or relevance here are:

- Testes
- Scrotum
- Seminiferous tubules (see below)
- Epididymis
- Vas deferens (see below)
- Prostate
- Penis

This picture shows the reproductive organs of a bull, but the function of each component is the same in males of all species.

The **testes** (or testicles) are the primary sex organs (*gonads*) of a male animal. Normal males have two testicles. Testes are firm oval-shaped structures that hang within the *scrotum* between the hind legs of the male and they are the site of production of *spermatozoa* (*sperm*) and the main male hormone (*testosterone*). Sperm cells are produced in the firm body tissue of the testes.

Note: testis is the singular form and is used when talking about only one testicle; testes is the plural form used when talking about both testicles.

The **scrotum** is a sack of skin located outside the animal's body cavity (hanging between the hind legs) that contains the testes. The testes are suspended within the scrotum by the spermatic cord which is attached to the body wall. The spermatic cord contains a suspensory ligament and muscles, the *vas deferens* and the blood vessels which supply the testes.

Temperature is very important for the development of healthy sperm and the ideal temperature is between 2 to 4°C lower than the normal body temperature, therefore the testes need to be held outside the animal's body. At higher temperatures sperm formation can result in the production of deformed sperm cells which leads to infertility.

In order to try to maintain the ideal temperature for sperm development the temperature of the testes can be partially regulated by varying the blood flow (higher flow means more warmth). Also a special muscle in spermatic cord can contract or relax to bring the testes closer to or further way from the abdominal wall (closer = warmer; further away = cooler). These actions are involuntary (automatic) and not under conscious control by the animal.

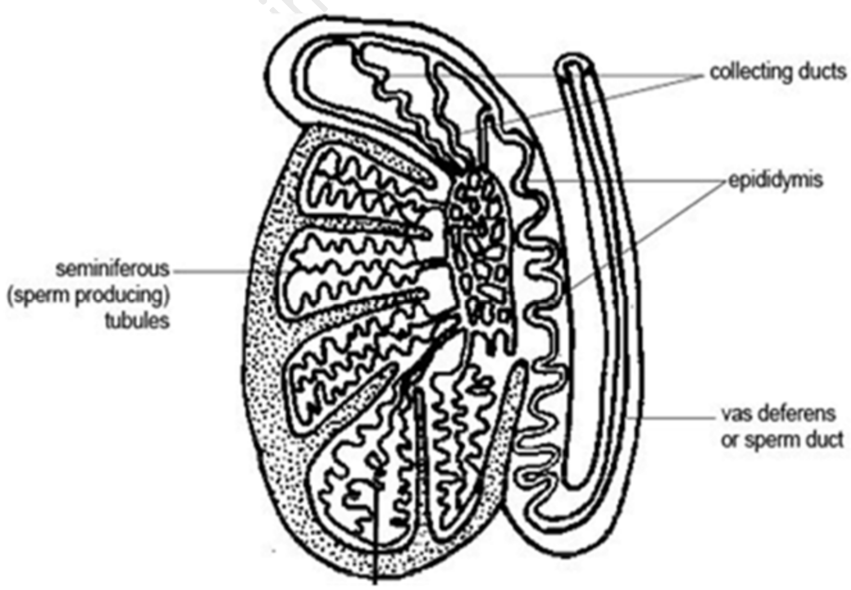

Figure 21 Diagram of a testis

Image retrieved from
http://wikieducator.org/The_Anatomy_and_Physiology_of_Animals/Reproductive_System_Worksheet

During male foetal development the testes normally develop inside the body cavity and 'descend' into the scrotal sac before birth. If this fails to occur during normal development the testes can remain in or close to the body cavity resulting in infertility due to excessive heat. In this condition the male is known as a *cryptorchid* – literally "hidden testes"). These animals are usually sterile and unable to breed.

The **seminiferous tubules** are the fine tubes within the body of the testes in which the sperm cells are produced. As with the female's eggs each sperm contains half the genetic material needed to make a fertilised embryo. After puberty, sperm is produced continuously. The process of producing sperm takes about 60 days and is influenced by temperature, day length and the animal's nutritional status.

The **epididymis** is a tightly coiled tube which lies on the surface of each testis. It is where the sperm produced in the seminiferous tubules of the testis are stored and develop until required at mating.

The **vas deferens** is a muscular tube which links the testicle to the urethra and penis. During mating it delivers the sperm stored in the epididymis to the penis from where it is ejaculated. The vas deferens normally runs up into the body cavity along with blood vessels and the ligament on which the testis hangs in the scrotum. Collectively these are known as the spermatic cord.

During ejaculation sperm is propelled through the vas deferens into the urethra and penis by contractions of smooth muscle in the walls of the tubes.

The **prostate** is a gland at the base of the bladder. The vas deferens passes through this gland. During mating this gland adds secretions to the sperm to form semen. These secretions provide fluid in which the sperm can swim and also help to nourish and protect the sperm in the female reproductive tract until fertilisation has occurred.

The **penis** is the male's organ of copulation. It is used to deposit sperm into the vagina of the female during mating.

The excretory (urinary) system

The excretory (urinary) system removes unwanted substances, including surplus water, from the body as well as the maintenance of homeostasis. Homeostasis is the constancy of the environment within the animal's body. The environment of the body's cells must be kept constant within narrow limits or else the cells stop functioning and die. The kidneys maintain homeostasis by regulating the concentration of minerals and water content of the blood, regulating the acidity/alkalinity (pH) of the blood and eliminating (removing) waste products (e.g. urea) and other substances (e.g. salts) if their concentrations get too high.

The main organs associated with the urinary system are the kidneys and the urinary bladder and their associated tissues and tubes.

The diagram below shows the arrangement of the kidneys and bladder in the urinary system of a cow. The arrangement is similar for sheep, horses and pigs.

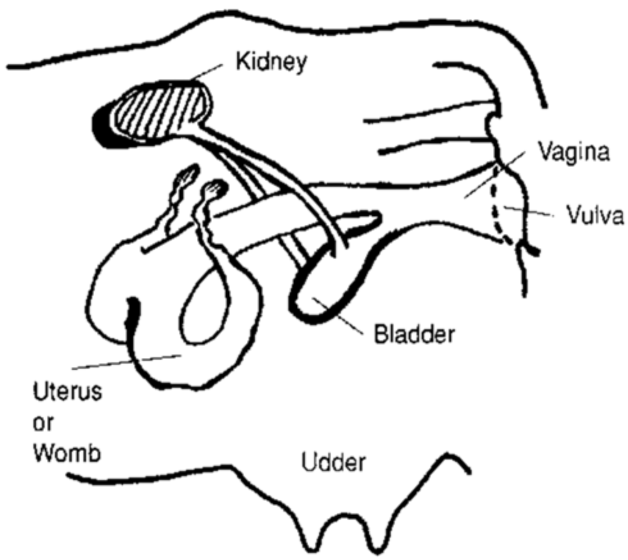

Figure 22 Position of kidneys in a cow

Image retrieved from http://www.fao.org/docrep/t0690e/t0690e04.htm

The first diagram on the next page shows the arrangement of the parts of the urinary system in more detail. In this case it is the urinary system of a human though the relationship between organs is the same in other mammals.

The *kidneys* are connected to the circulatory system from the aorta (the main artery from the heart) via the renal artery and the vena cava (the main vein returning to the heart) via the *renal vein*.

From each kidney a *ureter* carries urine from the kidneys to the *bladder*. The bladder is an elastic muscular structure which stores urine until it can be voided (*urination*). The exit from the bladder is controlled by a *sphincter*, a circular muscle which, when contracted, prevents urine escaping from the bladder. When it relaxes it allows urine to escape along the *urethra* to the external opening of either the male (penis) or female (urethral opening in the vulva), during urination.

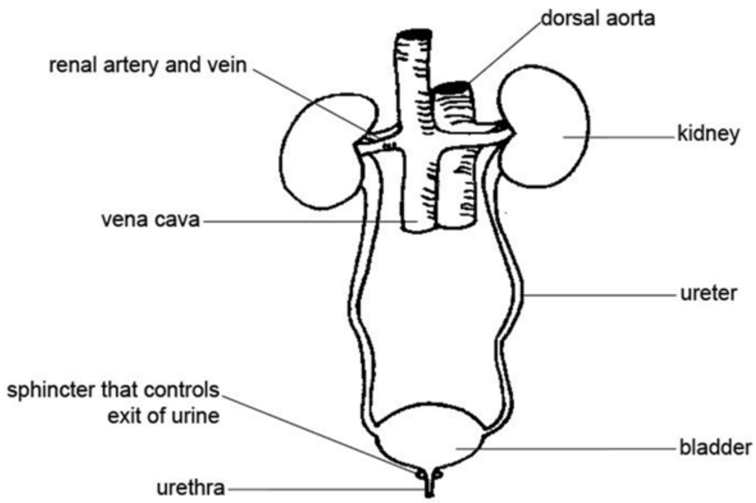

Figure 23 Details of the arrangement of the urinary system

The diagram above shows a cross section through a kidney to show the internal structure.

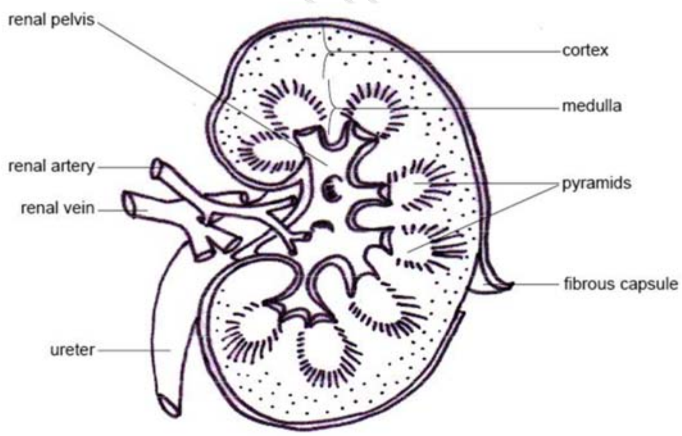

Figure 24 Cross section of a kidney

There are four distinct regions in kidney structure:

1. The **capsule**, a thin but tough membrane covers and protects the outside of the kidney.
2. The **cortex**, a dark and granular outer layer, is where the kidney does most of the filtering and it is rich in blood vessels.
3. The **medulla**, a pale coloured, stripy region is where the kidney creates the urine from filtered blood

4. The **renal pelvis**, a hollow area where the urine is collected before it descend through the ureter down to the bladder

In kidney failure the kidney is not able to filter out the waste products or control the mineral and water balance of the blood. This leads to gradual build-up of toxins and eventual death.

Sometimes salt crystals can form in the pelvis of the kidney. These may become too big to flush down the ureters. These can then block the ureters causing severe pain – these are kidney stones.

The Digestive system

The digestive system of any creature is the system of organs and tissues by which it obtains nutrients and water, digests them, extracts nutrients then expels any waster products. Overall the digestive system, its organs and tissues and the way it works is similar in all mammals. However, there are some variations in the different parts depending on the type of food the animal is adapted to eat. This is mainly to do with the digestibility and nutrient content of the animal's diet.

For example, carnivores (meat eaters, such as dogs) have sharp teeth, especially the canine teeth, and scissor-action molars to enable them to rip open and slice up their prey once they have caught it. Their digestive system is short and relatively simple because the meat that they eat is easy to break down and digest and has a high concentration of nutrients. In contrast, herbivores (plant eaters) have no canine teeth, but flat-topped molars adapted for grinding plant material and have long and more complex digestive systems than carnivores. These are adapted to extract the maximum amount of nutrients from relatively hard-to-digest plant materials. Omnivores (literally "eats anything") are animals that eat a wide variety of foods including both meat and plant materials (e.g. pigs), have a digestive system which have some features of both carnivores and herbivores.

The diagram below shows compares the digestive systems of a pig (an omnivore) and a cow (a ruminant herbivore).

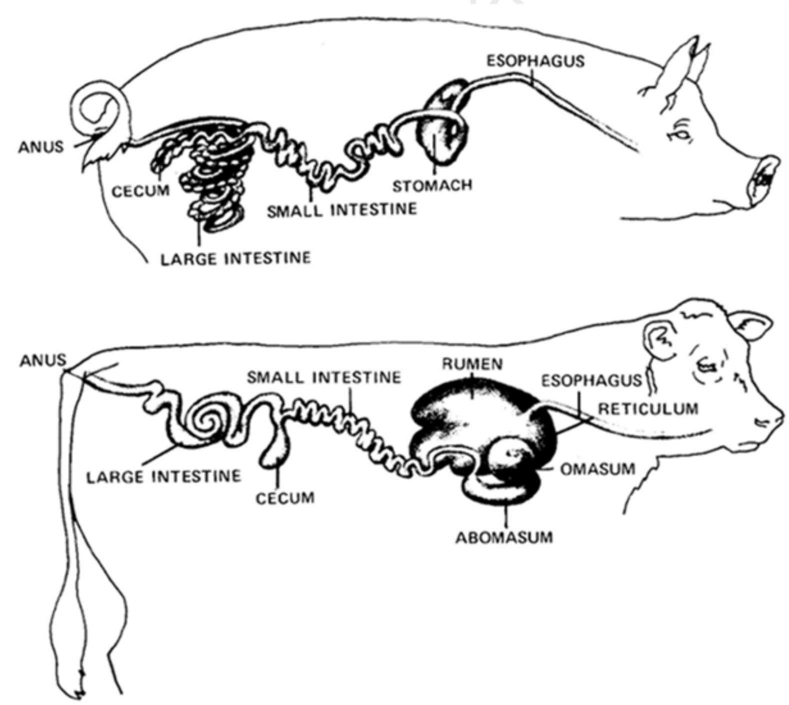

Figure 25 Digestive systems of a pig and a cow

Images retrieved from http://animaldigestion.weebly.com/ruminant-vs-non-ruminant

Farm livestock in New Zealand is mainly made up of herbivores (e.g. sheep, cattle goats and horses) and omnivores (e.g. pigs). One further complication is that although sheep, cattle and horses all rely on the same type of food, evolution has resulted in two different ways of dealing with the low digestibility of grasses and herbage diets; these are the ruminant and non-ruminant digestive system. We will look at both types, and how they differ, later in the module.

The components of the digestive system

The diagram below shows a generalised mammalian digestive system showing the main components and indicating their main functions. We will look at each component separately. Later we will look at the special adaptations of ruminant and non-ruminant digestive systems.

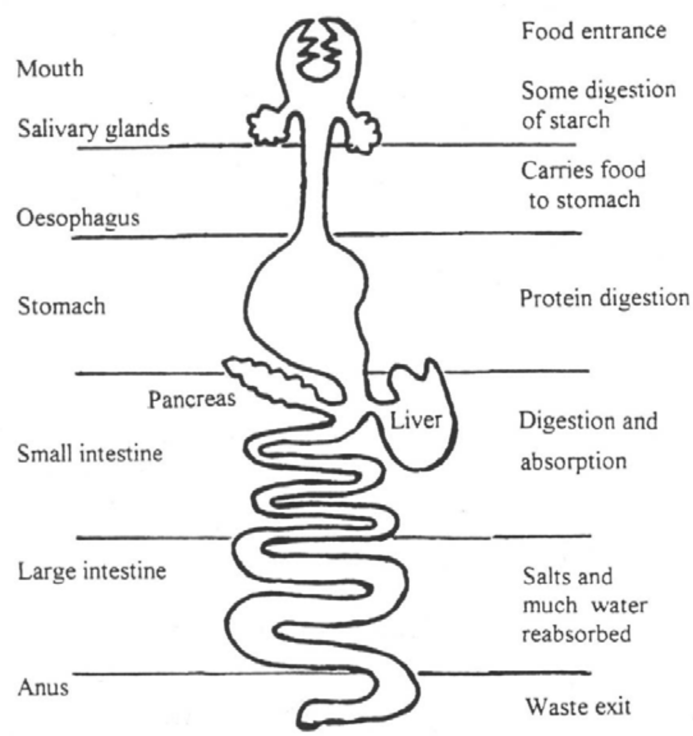

Figure 26 A generalised digestive system

Image retrieved from https://www.boundless.com/biology/textbooks/boundless-biology-textbook/animal-nutrition-and-the-digestive-system-34/digestive-systems-195/digestive-systems-745-11978/. Licenced under CC BY-SA 4.0

Mouth

The mouth is the start of the digestive tract and the means by which mammals obtain their food and begin the process of digestion. It is part of the pharynx discussed earlier when we looked at the respiratory system.

Using the mouth animals pick up their food, chew it with their teeth to start the process of breakdown for digestion, mix it with saliva and swallow it.

Salivary glands

Animals have several salivary glands in the mouth - in the roof, cheeks and under the tongue. Salivary glands have two main functions.

1. They secrete enzymes which help to begin the breakdown of nutrients in the food. An example is the enzyme amylase which begins to breakdown starch into sugars in the mouth.
2. They secrete mucus which aids in lubricating the food to make it easier to chew and to swallow.

Mucus and enzymes are secreted by different salivary glands.

Oesophagus

The oesophagus (gullet) is the muscular tube which connects the throat with stomach. It has muscular walls and moves swallowed food from the throat to the stomach. The oesophagus starts at the larynx, which acts as a valve to direct the food down the oesophagus, and prevents food from going down the trachea into the lungs. In ruminants the oesophagus also moves food from the stomach to the mouth for chewing (rumination - see later). Food is squeezed down the oesophagus by a muscular process called peristalsis. The same process moves food through the intestines. The ball of food is called a bolus. It is similar to the effect is produced when you squeeze toothpaste from a tube.

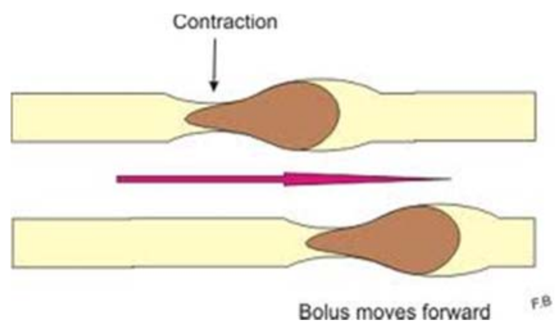

Figure 27 process of peristalsis

Image retrieved from https://en.wikibooks.org/wiki/Medical_Physiology/Gastrointestinal_Physiology/Motility.

Stomach

Food passes from the oesophagus into the stomach through a muscular ring known as the cardiac sphincter (as it is at the end of the stomach nearest the heart) and exits the stomach to enter the small intestine through another muscular ring known as the pyloric sphincter. The stomach is the first part of the digestive tract which has a major chemical breakdown action on food. The structure and function of the stomach varies in animals according to the diet.

In monogastric animals (literally – "one stomach") such as dogs, pigs and horses the stomach secretes acid and enzymes which begin to break down any proteins and fats which enter the stomach before the digested material (digesta) moves onto the next stage of digestion in the small intestine.

In ruminants, the stomach is modified into 4 chambers which are adapted to give the animal the opportunity to break done and extract some of hard-to-digest nutrients in herbage before it goes through the acid digestion and enters the small intestine. We will go into this in more detail later.

Small intestine

Digestion of food and absorption of nutrients takes place in the small intestine. More enzymes are secreted into the intestine by the pancreas and bile from the liver to help digestion. Amino acids (from protein) and sugars (from starch) are absorbed in this part of the intestine as the digesta moves along the small intestine. The process is similar in both monogastric and ruminants.

Liver

The structure of the liver is very similar in all mammals. It is the largest internal organ in the body. It lies directly under and against the diaphragm, in front and to the right of the stomach and is divided into two lobes, each of which is further sub-divided. The liver takes the shape of the space that is available to it, and it also has a remarkable ability to regenerate itself if any of the tissue is damaged or has to be removed due to disease.

The liver performs many chemical functions for the body and is also closely associated with the digestive process:

- Protein metabolism: For example the proteins involved in blood clotting.
- Urea formation: when proteins are broken down by the body, ammonia, a toxic substance, is formed. This is converted to less toxic urea in the liver, which is then excreted by the kidneys.
- Carbohydrate metabolism: the liver helps to keep blood sugar levels within narrow limits. Excess glucose is stored in the liver as glycogen then released into circulation again as glucose when energy is needed by the body. It does this in response to insulin from the pancreas.
- Fat metabolism: some fats required by the body are made in the liver, and fatty acids are metabolised in the liver to produce energy.
- Detoxification and removal of many chemical substances and waste products from the blood.
- The production of heat and regulation of body temperature.
- Iron and vitamin storage, especially the storage of fat soluble vitamins A, D, E and K.
- Storage of the water soluble B vitamins, especially B12.

Gall bladder

Not all mammals have a gall bladder (horses and deer do not), but when it is present it is found under the lobes of the liver. Bile is a fluid created in the liver which contains water, bile salts and other substances such as waste products from the breakdown old red blood cells and haemoglobin in the liver. Bile salts help to break fat down into microscopic droplets (in the same way that detergent works in washing up liquid). The smaller fat droplets are easier to absorb in the small intestine. Bile is stored in the gall bladder and released into the intestines as needed.

Pancreas

The pancreas is a gland with two functions relating to digestion:

1. It secretes digestive enzymes which aid in the digestin of proteins and other nutrients in the small intestine. These enzymes enter the intestine through a duct called the pancreatic duct.
2. It secrets insulin which the body uses to regulate the glucose concentration in the blood. If blood glucose is in excess after a meal the pancreas secrets insulin which encourages the liver to store it away as glygogen.

Large intestine (and caecum)

The large intestine is also known as the colon. By the time the digesta gets into the large intestine, many of the nutrients have already been digested and absorbed earlier in the small intestine. But some absorption of nutrients also takes place in the colon, particularly mineral salts. Also water from feed and also that secreted into the intestinal tracts along with enzymes is reabsorbed.

The large intestine is also an organ which varies quite dramatically according to the diet the animal is adapted to. In carnivores which have highly digestible food, the large intestine is relatively short because all the valuable nutrients are absorbed earlier in the digestive tract.

In ruminants, the large intestine is also relatively small because the hard-to-digest plant material has been broken down and digested in the rumen. However in horses and pigs, the stomach and small intestines are not able to digest much of the valuable plant nutrients in the feed so it goes through into the large intestine which is modified into a much larger organ. It is here where the remaining indigestible plant materials are processed and nutrients absorbed.

Therefore ruminants digest plant material before it goes through the stomach. In comparison horses and pigs digest plant material after it goes through the stomach – though horses and pigs do it slightly differently! We will look at this in more detail below.

Rectum and Anus

The last portion of the colon is known as the rectum. This is the part where faeces is consolidated and briefly stored before it is expelled through the anus. The anus is the ring of muscle (sphincter) that keeps the colon closed.

Test Yourself #2

The answers to the following are all in the notes, but try to answer the questions without looking back at your notes to test how much you have learned.

1. Place the components listed below into the appropriate column of the table, depending on which body system they are a part of:

heart; lungs; spinal cord; arteries; testes; trachea; vena cava; neuron; small intestine; bronchi; penis; veins; liver; pharynx; oesophagus; brain; capillaries; colon; diaphragm; dendrites; teeth; uterus; aorta; scrotum; larynx; ovaries; stomach; cervix; nerve endings

Circulatory	**Digestive**	**Respiratory**	**Reproductive (male and female)**	**Nervous**

2. List the functions of the following body systems:

Circulatory	
Respiratory	
Reproductive	
Digestive	
Nervous	

Ruminant and non-ruminant digestion

In the previous section we saw how the general anatomy, physiology and the processes of digestion are similar in all mammals except for a few differences and modifications.

The main differences in anatomy and digestive processes between ruminants (sheep, cattle, goats) and non-ruminants (horses and pigs) is in the modifications of the stomach and large intestine. These have become adapted to break down hard-to-digest plant fibres that form a large part of their diet.

Plant material has a lot of valuable soluble nutrients such as sugars, proteins and other nutrients. These nutrients are contained inside the plant cells. These are released when the animal chews the plant material and breaks up the cell walls, releasing the contents. However, plants also contain a lot of fibrous material made up of cellulose and lignin which strengthen the plants cell walls. Cellulose and lignin are part of the family of chemical compounds called carbohydrates (which includes sugars and starches) but they are extremely difficult for animals to digest. Mammals can produce their own enzymes to digest sugars and starches but they are unable produce enzymes which can digest and breakdown cellulose and lignin.

The problem is that animals would not be able to eat enough plant material if they were to rely on the soluble cell nutrients alone. They would never be able to eat enough to satisfy their requirements. However, herbivores have evolved to recruit the help of bacteria, protozoa and fungi that can produce enzymes to digest cellulose and lignin. These organisms behave in a similar way to those that break down plant material in a compost heap.

Herbivores have evolved a special partnership with these microbes. They create an environment inside their own digestive systems in which these microbes can live and reproduce. In this environment the microbes break down the cellulose and lignin to feed themselves and at the same time produce nutrients that the herbivores can also absorb and use. The partnership provides a safe environment for the organisms, and a personalised plant digesting service for the herbivores.

The process by which the microbes digest the food on behalf of the herbivores is called fermentation. The difference between the fermentation in ruminants and non-ruminants is that in ruminants the fermentation of plant material takes place before it goes through the stomach (in the rumen); in non-ruminants it takes place largely in the large intestine. In biological terms ruminants are known as fore-gut fermenters (at the front end of the gut), and non-ruminants as hind-gut fermenters (at the rear end of the gut).

Ruminant Digestion

The main characteristic or anatomical feature which defines a ruminant is the rumen. The rumen is a structural modification of the single stomach found in most animals. It is known as a compound stomach because it is made up of four chambers instead of one. The diagram below shows the anatomy of the rumen in a cow. It is almost exactly the same in sheep and goats (but smaller overall).

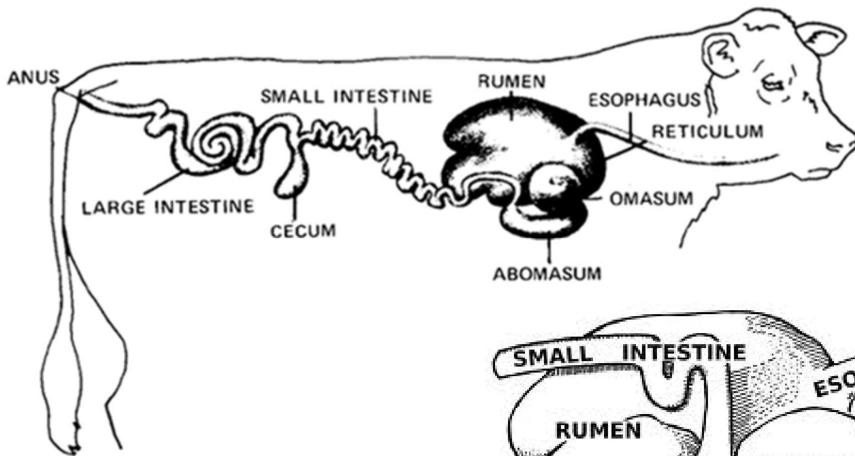

Image of cow retrieved from http://animaldigestion.weebly.com/ruminant-vs-non-ruminant

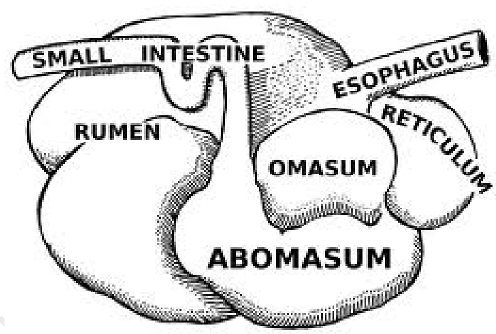

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Figure 28 Anatomy of the rumen

The compound stomach of the ruminant lies in the left side of the body and takes up about 70-80% of the abdominal cavity. Watch a standing cow after it has been grazing and you may be able to see the rumen moving on one side of the animal.

The rumen (its full name is the reticulorumen) consists of four separate chambers connected in series (one after the other). In order (from the oesophagus) they are; the reticulum, rumen, omasum and abomasum. Each has a particular part to play in the digestive process:

- The **reticulum** is a small pouch where the oesophagus enters into the rumen. Digesta (partially digested food, the contents of the gut undergoing digestion) enters and leaves the rumen via the reticulum. The reticulum is also involved in the reflex by which ruminants regurgitate partially digested grass to be re-chewed before being swallowed again (rumination). The digesta content of the reticulum is very similar the rumen.
- The **rumen** is the largest chamber and makes up about 80% of the volume of the compound stomach. The contents of the rumen are usually very coarse and fibrous (blades of grass or stalks of hay can be seen) and also very watery due to the large amounts of saliva produced. This is the part

of the rumen where the majority of the fermentation of plant fibres by rumen microbes takes place. The rumen wall also absorbs volatile fatty acids (released by the microbes) which the ruminant can use as an energy source in it metabolism.

- The **omasum** is a small round organ found to the right of the reticulum and rumen. On the inner surface, it has many broad, flat folds of tissue, similar in appearance to the leaves of a book. The purpose of the omasum is to filter and regulate the flow of digesta from the rumen, allowing only small particles into the abomasum for further digestion. It also absorbs water so that the digesta flowing to the abomasum is more concentrated. The digesta found in the omasum is usually very fine fibrous material and is drier than the digesta found in the reticulum and rumen.
- The **abomasum** is the true stomach of a ruminant and has a glandular lining similar to that found in the stomach of a non-ruminant. The function of the abomasum is the same as that in a in a non-ruminant animal – acid digestion of proteins and fats (see earlier).

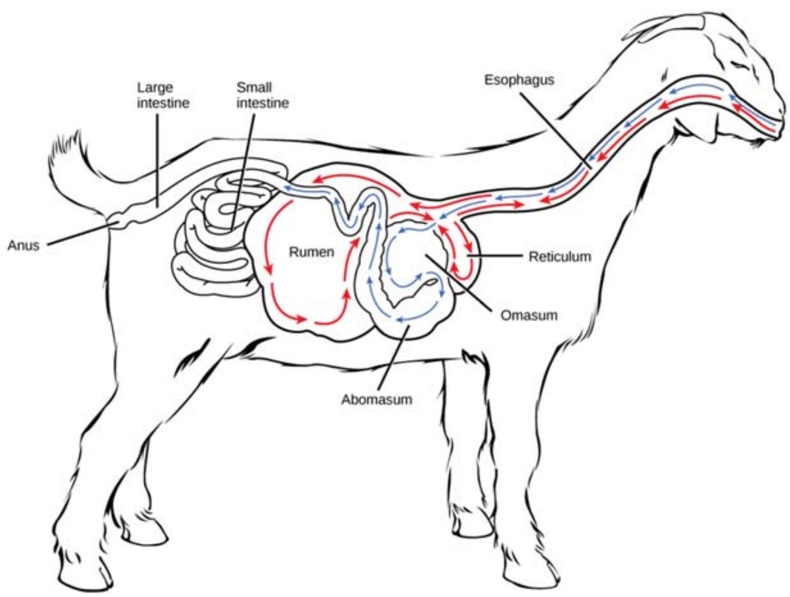

Figure 29 Movement of food through the rumen in a goat

The process of ruminant digestion is as follows:

Grazing: Grazing ruminants do not usually chew up their food as they graze. They usually graze twice a day (morning and evening) and during this time they simply graze the pasture to fill up the rumen. They chew the pasture only until it is small enough to swallow into the rumen. Ruminants produce copious quantities of saliva during this process to aid swallowing.

During and immediately after grazing the rumen contents are still very fibrous and the individual grass blades, stalks and seed heads are largely intact. The rumen microbes start to work digesting the soluble nutrients released by grazing and on the cellulose and lignin in the plant cell walls.

Rumination: After grazing the animal rests and ruminates. Rumination (chewing the cud) is the process by which the partially chewed food stored in the reticulum and rumen is regurgitated into the mouth and chewed again to break it down into much finer particles, and then these are swallowed once more. Each mouthful of food that is regurgitated is chewed about 40-50 times, so is much more thoroughly broken down than when it was initially eaten. This increases the surface area of the particles in the rumen which makes it much easier for the rumen microbes to digest it further.

Grazing cattle will spend about 8 hours a day ruminating, about the same time as they will spend grazing.

During and after rumination the rumen contents ferment rapidly and the consistency becomes more liquid as the particle size of the pasture fragments is reduced by rumination and microbial digestion. During this time the muscular walls of the rumen contract and churn the contents to mix it up and aid fermentation. This movement can sometimes be seen in ruminating animals – the left side of the animal bulges and moves. At this stage the rumen microbes ferment cellulose and lignin into glucose and volatile fatty acids (acetic acid, butyric acid and propionic acid). Most of these are absorbed directly through the walls of the rumen into the ruminant's bloodstream. These are then used in the animal's normal body metabolism.

A lot of heat is also generated by rumen fermentation. This can be very valuable to animals in cold conditions. Well-fed animals with a full heat-generating rumen can withstand cold conditions much better than those with "an empty stomach". This is another reason why it is especially important to get feed to livestock stock stranded in snowy conditions.

During this time the rumen microbes are growing, reproducing and proliferating in the rumen using the nutrients released from the herbage to build their own cellular proteins and structures. These nutritious microbes then also become a source of protein and nutrients to the ruminant.

Digestion: When the particle size of the rumen contents is small enough it filters through into the omasum where water is absorbed (so the digesta becomes much drier) and then into the abomasum (the true stomach) where gastric juices and acids are secreted to begin the digestion of protein.

Many of the microbes which grow in the rumen also flow through the omasum into the abomasum and so become a major nutrient source for the ruminant.

From the abomasum onwards the processes of digestion and absorption in the intestines is very similar to that of monogastric animals.

Note: Because cattle do not chew their food before they initially swallow it, they can easily pick up and swallow foreign objects such as wire. These tend to accumulate in the reticulum and can cause problems if they pierce the wall of the reticulum, especially because the reticulum lies so close to the heart.

Bloat

During the digestive processes in the rumen a lot of gas is produced, which the animal usually gets rid of via the mouth by belching (eructation). If for any reason the animal cannot get rid of this excess gas, they are likely to bloat and may die. This can occur if the animal has become cast on its back (common in sheep) or eats certain types of feed which cause the rumen contents to foam, blocking the oesophagus and preventing the release of gas. Bloat can be prevented by using special bloat oils which help to prevent foaming in the rumen.

Non-Ruminant Digestion:

Non-ruminant herbivores (e.g. horses) and omnivores (e.g. pigs) have a simple stomach designed primarily for the acid digestion of proteins. In non-ruminants the process of digestion is largely as explained earlier in the generalised digestive system. Horses do not graze intermittently in the same way as cattle. They do not have large stomachs to store herbage, so horses need to graze more or less continuously. Horses chew their food more than ruminants do to break down the fibre, but once swallowed the particle size is not mechanically broken down any further.Like ruminants they cannot produce enzymes which can break down the hard-to-digest cellulose and lignin of plant materials. However, like ruminants they can recruit bacteria, fungi and protozoa to help in this process. In non-ruminants these are contained in the caecum and large intestine.

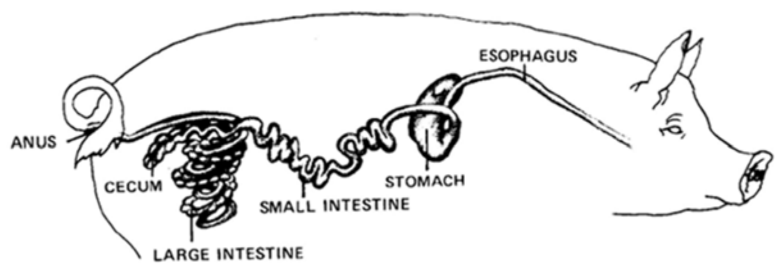

Figure 31 Non-ruminant (monogastric) digestive system of a pig

Image retrieved from http://animaldigestion.weebly.com/ruminant-vs-non-ruminant

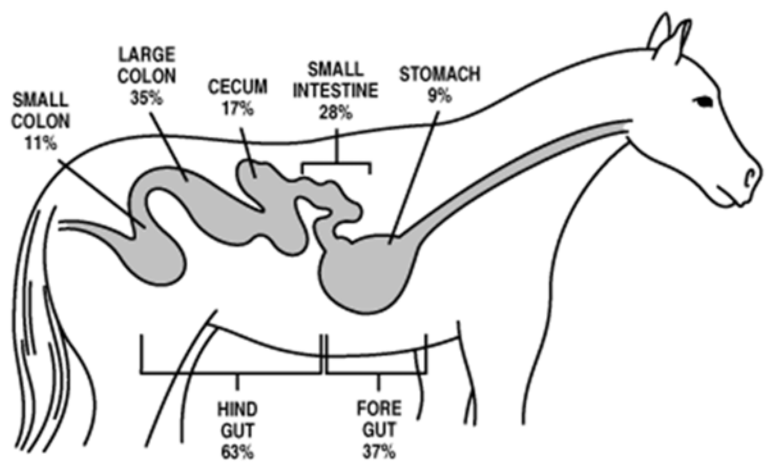

Figure 31 Non-ruminant (monogastric) digestive system of a horse

Image retrieved from http://becuo.com.forsearch.net/horse-digestive-system-diagram

In horses and pigs, at the junction of the small and large intestines there is a closed sac known as the caecum or 'blind sac'. There is a non-functional remnant of this in humans – the appendix. In pigs the caecum is large but not as big as in horses. In horses the caecum is very large – it has a capacity of many litres. The caecum contains an active microbial population, which helps in the digestion of cellulose based foods by splitting the cellulose into simpler, easily absorbed substances. The caecum is sometimes compared to the rumen of ruminants because cellulose digestion takes place there, but it is much less effective than the rumen in the amount of fibre that it can digest. Horses do not re-chew herbage (chew-the cud) like ruminants do so the fibre particle size remains quite large all through the digestive tract. This is why the faeces of horses are very fibrous compared to that of cattle and sheep.

After microbes have extracted nutrients from the digesta in the caecum it passes into the large intestine or colon, where much of the remaining water is absorbed and the faeces are concentrated. Some further digestion of cellulose also occurs in the colon, broken down by more bacteria and microbes which thrive there. As in ruminants microbial fermentation of plant materials produces a lot of gas. In non-ruminants this escapes through the anus (flatus).

A comparison of ruminant and non-ruminant digestion

Ruminant	**Non-Ruminant**
• Food is swallowed after very little chewing	• Food is initially chewed thoroughly to break it down into pieces small enough to be swallowed comfortably. The action of saliva starts to partially digest starches.
• Complex, compound stomach made up of four chambers: rumen, reticulum, omasum and abomasum.	• Simple, one chamber stomach used for storage and mixing.
• Food initially enters the rumen and reticulum, where fermentation and digestion of the plant material begins. Large volumes of saliva are produced and added to the food in the rumen. The material is regurgitated and chewed thoroughly to break down the tough plant material before being swallowed once more (rumination or chewing the cud).	• Non-ruminants do not regurgitate and re-chew their food
• Some glucose and other organic acids are absorbed directly through the walls of the rumen; water and some fats are absorbed in the omasum; the digestion of protein begins in the abomasum.	• Digestion of some proteins begins in the stomach.
• Absorption of nutrients takes place in the small intestine	• Large amounts of digestive enzymes and mucous are produced in the small intestine • The majority of the absorption of useful nutrients (carbohydrates, fats, proteins, vitamins and minerals) takes place in the small intestine
• Water is absorbed and the faeces concentrated in the large intestine	• Some digestion of protein occurs in the large intestine • Some digestion of cellulose is possible in the large intestine, broken down by the bacteria that live in the caecum and large intestine. • Water is absorbed and the faeces concentrated in the large intestine
The ruminant digestive process allows the animal to extract nutrients from cellulose-rich plant material.	Non-ruminants cannot extract as much nutrient value from cellulose-rich feed as ruminants can

Test Yourself #3

The answers to the following are all in the notes, but try to answer the questions without looking back at your notes to test how much you have learned.

Complete the following table comparing and contrasting ruminant and non-ruminant digestion:

	Ruminant digestion	**Non-ruminant digestion**
how food is chewed and swallowed		
stomach: size, function, complexity,		
function of small intestine		
function of large intestine		
efficiency of digestion of plant material		

Answers to the Self Test Questions

Test Yourself #1

1. *False - bones are living tissues and are constantly being renewed and replaced*
2. *True*
3. *True*
4. *True*
5. *False - tendons are made of thin sheets of dense white, fibrous tissue*
6. *False - the skin does receive stimuli from the environment and animals have very sensitive skin (think of a cow or horse twitching when a fly lands on its skin)*
7. *True*
8. *False - cardiac muscle is the muscle that keeps the heart beating and this action is involuntary*

Test yourself #2

1. *Place the components listed below into the appropriate column of the table, depending on which body system they are a part of:*

Circulatory	***Digestive***	***Respiratory***	***Reproductive (male and female)***	***Nervous***
heart; arteries; veins; aorta; vena cava; capillaries;	*small intestine; colon; teeth; liver; stomach; oesophagus;*	*lungs; trachea; larynx; bronchi; diaphragm; pharynx;*	*testes; penis; uterus; scrotum; ovaries; cervix*	*brain; neuron; dendrites; nerve endings; spinal cord*

2. *List the functions of the following body systems:*

Circulatory	*to carry blood around the animal's body: delivers oxygen and nutrients to each cell in the body and removes waste products and carbon dioxide from each cell.*
Respiratory	*allows animals to breath – take in air that is rich in oxygen and exhale air that is rich in carbon dioxide.*
Reproductive	*the system by which animals produce offspring which will ensure the survival of the species into the next generation.*
Digestive	*allows the animal to take in food, process it so that useful nutrients can be extracted, then get rid of the waste products of this processing.*
Nervous	*receives information from the outside environment, processes it and allows the animal to make appropriate responses – stimulates movement and/or behaviour*

Test yourself #3

1. *Complete the following table comparing and contrasting ruminant and non-ruminant digestion:*

	Ruminant digestion	***Non-ruminant digestion***
how food is chewed and swallowed	*food is not chewed very much before being swallowed*	*food is chewed thoroughly before being swallowed*
stomach: size, function, complexity,	*4 stomachs; complex structure; rumen very large; function to break down plant material and start the digestion of cellulose*	*Only one stomach; simple stomach structure; stomach acts more for storage than breakdown and digestion of food*
function of small intestine	*Absorption of nutrients*	*Digestive enzymes produced and absorption of nutrients takes place*
function of large intestine	*Absorption of water from digesta; faeces is concentrated*	*Some digestion of proteins; some digestion of cellulose is possible; water is absorbed and faeces concentrated*
efficiency of digestion of plant material	*Very efficient at digesting plant material; obtain lots of nutrients*	*Not very efficient at digesting and obtaining nutrients from plant material*