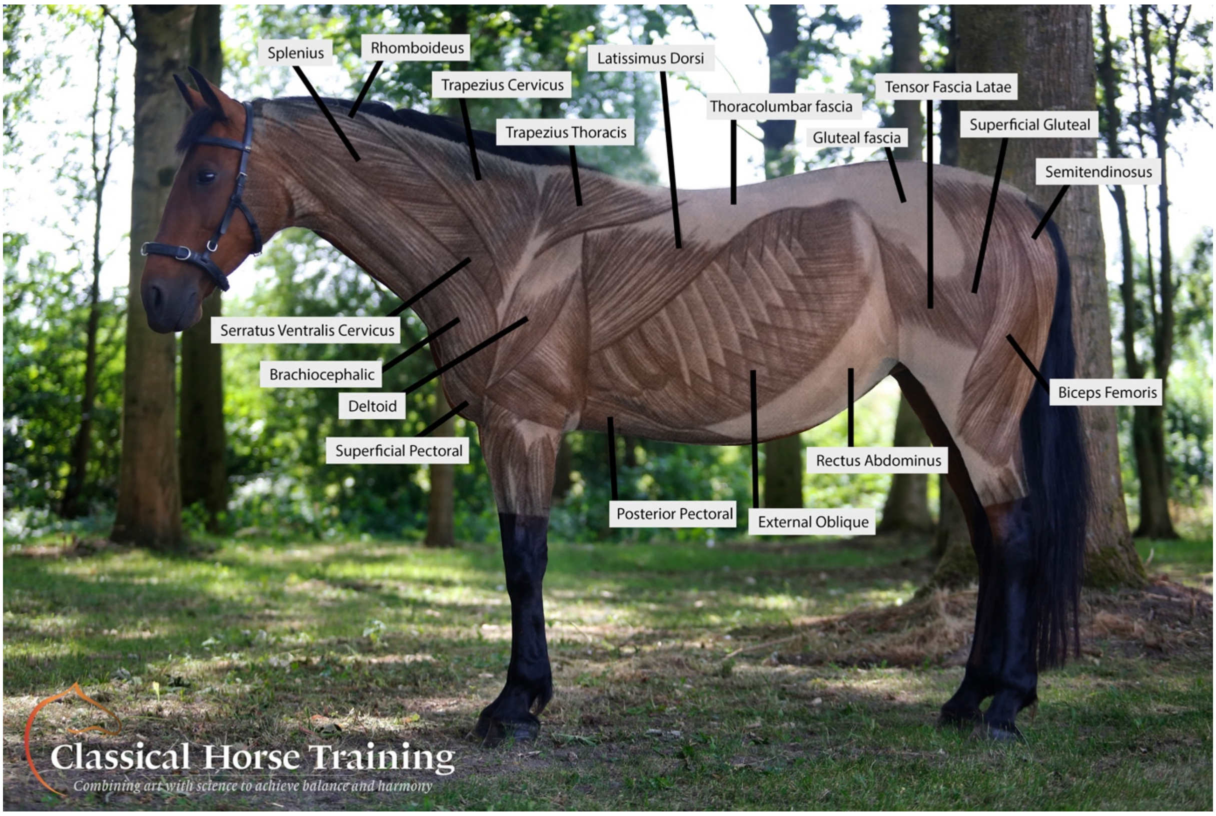

Mechanisms explained:

Basic Anatomy

"LIVE AS IF YOU WERE TO DIE TOMORROW. LEARN AS IF YOU WERE TO LIVE FOREVER." —MAHATMA GANDHI

MANUAL

FOREWORD

This manual aims to give you a compact overview and understanding of basic equine anatomy & biomechanics. It is a collection of knowledge gathered from years of study and experience. My understanding of these topics is heavily influenced by participating and organizing numerous whole horse dissections. For me, this truly provides the opportunity to learn from horse 'inside-out'. Bones and muscles don't lie and therefore a dissection can be considered as 'revealing the facts'. Facts do not cease to exist because they are ignored.

The information in this manual has proven to be a key factor to successfully rehabilitate horses with various injuries or limitations as well as preventing future injuries in sound horses.

The information might be a bit overwhelming and theoretical at first. I totally get that feeling as I myself didn't have a background in equine science. In fact, I was just a very novice horse rider trying to understand my horse. I went into a dissection with no prior knowledge of anatomy & biomechanics at all, apart from what was told by my riding instructors. Afterwards I was amazed and confused at the same time. I realized I knew nothing.
I had been trying for years to train my horse according to people's opinions based upon tradition instead of considering to learn from the truths of my horse's body that was right in front of me. Deep down I always felt that she wasn't 'naughty', but my ignorance didn't allow me to provide a solution. You cannot do what you do not know. Being ignorant is not a shame, only being unwilling to learn.

Studying anatomy & biomechanics is a continuous process in which we must realize that the more we learn, the less we actually know. Therefore, give yourself time. It is okay to feel overwhelmed and confused at first as it is needed for change. My biggest break through always came after periods of feeling uncomfortable and completely out of my comfort zone. After my first dissection and studying all kinds of materials I tried to really closely observe rotations in my horses legs and the movement of their pelvis. I couldn't make anything out of it. I felt very insecure. But I just knew there was no going back as I could not unsee what I had seen in the dissection as well as the negative effect of many training practises. So I kept ‘muddling’ through and slowly, I started to see. My senses – smell, eye, hearing and feel – started to develop and I started to recognize patterns, differences and abnormalities. It was a slow process – and still is – but it literally saved my horse’s life and many others after.

I want to encourage you that even though it might seem overwhelming, to dive into this learning journey about your horse ‘inside-out’. It is my wish that some of this content might give you a deeper understanding of your equine partner, improving its quality of life and longevity while optimizing your relationship and performance in balance and lightness.
The first step usually is the biggest and always remember that anything worth doing, is worth doing poorly at first: *‘’The master has failed more than the beginner ever tried’’.*

NOTE OF THANKS

I am forever grateful to the amazing Sharon-May Davis and Zefanja Vermeulen for influencing my learning processes through the horse inside-out principle.

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DISCLAIMER

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DEFINITION

When looking at its definition, anatomy is defined as:

> *''The branch of science concerned with the bodily structure of humans, animals, and other living organisms, especially as revealed by dissection and the separation of parts.''*

In other words, anatomy is studying the architectural framework of the horse. This framework has to be resilient in order to produce movement and to withstand all kinds of internal and external forces. It is a beautiful and ingenious arrangement consisting of multiple parts or layers that makes up a holistic whole. The anatomical design of the horse also provides the foundation for studying movement (biomechanics).

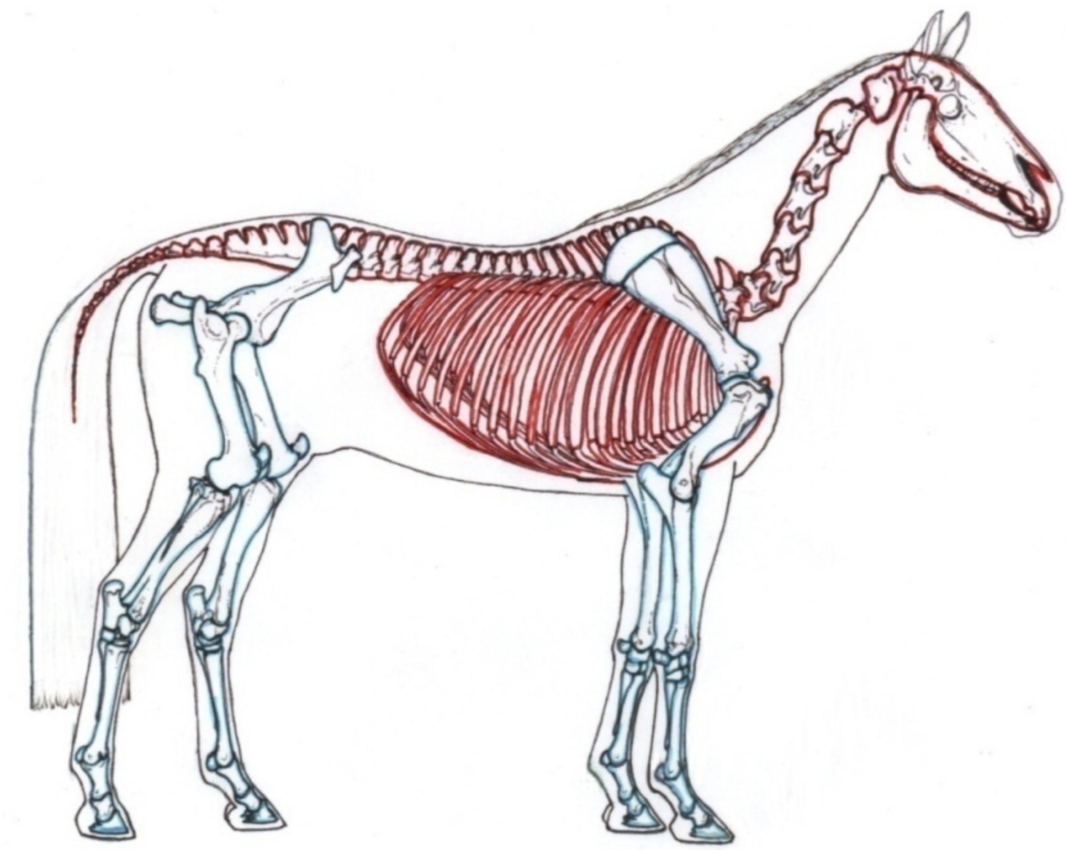
In the following chapters, I will elaborate on each individual layer and its connections.

SKELETON

The skeleton forms the boney framework of the horse with an average of 205 bones - with variations up till 18 bones.

The equine skeleton consists of an axial and appendicular part. The axial part includes the skull, vertebrae, ribs, sternum and manubrium whereas the appendicular part consists of the thoracic (front) and pelvic (hind) limbs, including the pelvis. Unlike humans, horses don't have a collarbone connecting the forelimbs to the trunk[1].

[1] See *videos & manual: Engaging the thoracic sling for more information*



Picture showing the axial (red) and appendicular (blue) parts of the skeleton

The total number of bones can be divided accordingly:

LOCATION	NUMBER OF BONES
Skull	34
Sternum / Manubrium	1
Vertebral column	49-54
Cervical	7
Thoracic	17-19
Lumbar	5-6
Sacral	5
Caudal	15-22
Ribs	34-38 both sides
Front limbs	38-40 both limbs
Hind limbs	38-40 both limbs

Some of the variations correspond with breed. For example, an Arabian horse usually has 17 thoracic and 5 lumbar vertebrae whereas a warm blood typically shows 18-19 thoracic and 6 lumbar vertebrae. Variations are of importance depending on the desired athletic purpose for a horse. For example, in selecting a race horse or jumping horse, having at least 18 thoracic vertebrae is desired as this provides more room for a better heart/lung capacity.

Apart from breed, variations and abnormalities can also occur within the individual. For example, horses can have 17 ribs on one side and 18 to the other. Abnormalities include floating ribs and transitional vertebrae. A transitional vertebrae either is a rib thinking it is a vertebral process, or a vertebral process thinking it is a rib.

Picture of a fused floating rib on the lumbar transverse process. The rib was first floating and then somehow started to attach. This is different to a transitional vertebrae and really shows the amount of variations possible within the individual.

The main functions of the skeleton are:

- **Support** → Bones provide the framework for the body and is the hardest structure in the horse's body after the teeth.
- **Protection of vital organs** → For example: the skull protecting the brain; the entire structure is centred to protect the spinal cord
- **Movement** → through the action of skeletal muscles
- **Manufacturing of blood** → red blood cell formation occurs in the bone marrow of the medullary cavity, mostly found in the centre of all 'long' bones. For example: femur, tibia, radius and all cannons.
- **Storage of minerals** → particularly calcium and phosphorus. They facilitate many reactions necessary for survival. Example: chemical aids in rapid muscle

BONE TYPES

Bones can be classified into five categories according to their shape:

- **Long bones** → These literally long bones contain marrow and have joint surfaces at either end. They support body weight, act as levers for muscle attachment and manufacture new blood cells. Examples are: *Cannon bones, Radius, Tibia, Femur* and *Humerus*.
- **Short bones** → These strong and compact bones aid in absorbing concussion. Examples are the short *pasterns, carpal bones in the knees* and *tarsal bones in the hocks*.
- **Flat bones** → These bones have broad and flat surfaces and help enclosing cavities containing vital organs as well as providing large areas for muscles attachments. Examples are: *ribs, skull, scapula* and *sternum.*
- **Irregular bones** → These irregular shaped bones serve various purposes through the body. Examples are the *vertebrae* that protect the central nervous system.
- **Sesamoid bones** → These bones lie within tendons and ligaments behind the bones of the fetlock. They add strength and help protecting these tendons

and ligaments as they pass around over bony surfaces to ensure correct functioning. Examples are the *navicular* and *patella.*

Pictures Adapted from Gillian Higgins 2009. From left to right: long cannon bone, short carpal bone, flat scapula, irregular vertebrae and sesamoid.

BONE COMPOSITION

Although bone is often considered inactive or static, it actually is a very active and dynamic tissue that is constantly undergoing change, responding to physical forces, metabolic and nutritional changes and hormones.

In the mature horse, the basic structure of bone includes about 1/3 organic material such as cells and 2/3 inorganic materials such as osteoid and minerals. The organic material is composed by three types of cells:

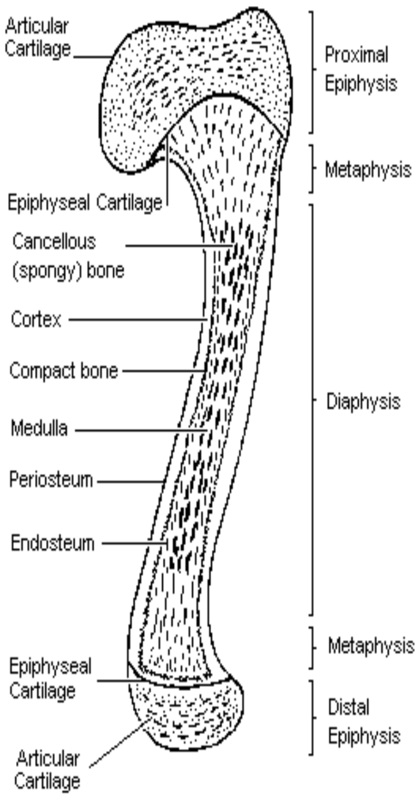
- **Osteoblasts** → These are bone-forming engines directing the formation and hardening of the bone.
- **Osteoclasts** → These are reabsorbing cells that break down the bone, opposing the osteoblasts
- **Osteocytes** → These control the relative balance of both osteoblast and osteoclast activity. These cells can sense changes in bone loading and initiate an appropriate modelling or remodelling response.

The inorganic material is primarily composed of osteoid and minerals. Osteoid is an organic, uncalcified homogeneous substance that consists of the protein collagen (90%) which resists tension and furthermore some bone-specific proteins (10%) including osteonectin, osteopontin and osteocalcin. The mineral component primarily consists of calcium phosphate (80%), calcium carbon (20%) and magnesium phosphate. This is what gives bones its hardness and strengths. In total, the mineral component accounts for 65%-70% of the bone.

Together, all the components of bone are arranged to give maximum strength for minimum weight.

BONE STRUCTURE

To study the structure of bone, it is easiest to look at a typical long bone such as the cannon bone in which we see the following characteristics:



- **Periosteum →** The periosteum is a specialized sheet of connective fibrous tissue covering the outer surface of bone, except at the articular surface, which is covered by articular cartilage. It consists of a rich supply of nerves and lymph vessels.

- **Cartilage →** This is the smooth, dense substance which covers the end of a bone where it meets other bones at a joint. It helps to absorb concussion and minimise friction.

- **Compact or cortical bone →** This is the hard outer layer, formed by a densely packed network of microscopic (haversian) canals containing blood vessels which supply nourishment for continuing growth and development. It is arranged to resist the stresses it must bear.

- **Cancellous or spongy bone →** This is located inside the compact bone. Differently than its name suggests, spongy bone is spongy by appearance only, not in hardness. In fact, it consists of the same materials as compact bone, but just arranged differently

- **Medulla →** The central cavity inside the spongy bone

- **Bone marrow →** This is contained within the medulla and forms red blood cells. As the horse ages it is partly replaced by fat, changing colour from bright red to yellow

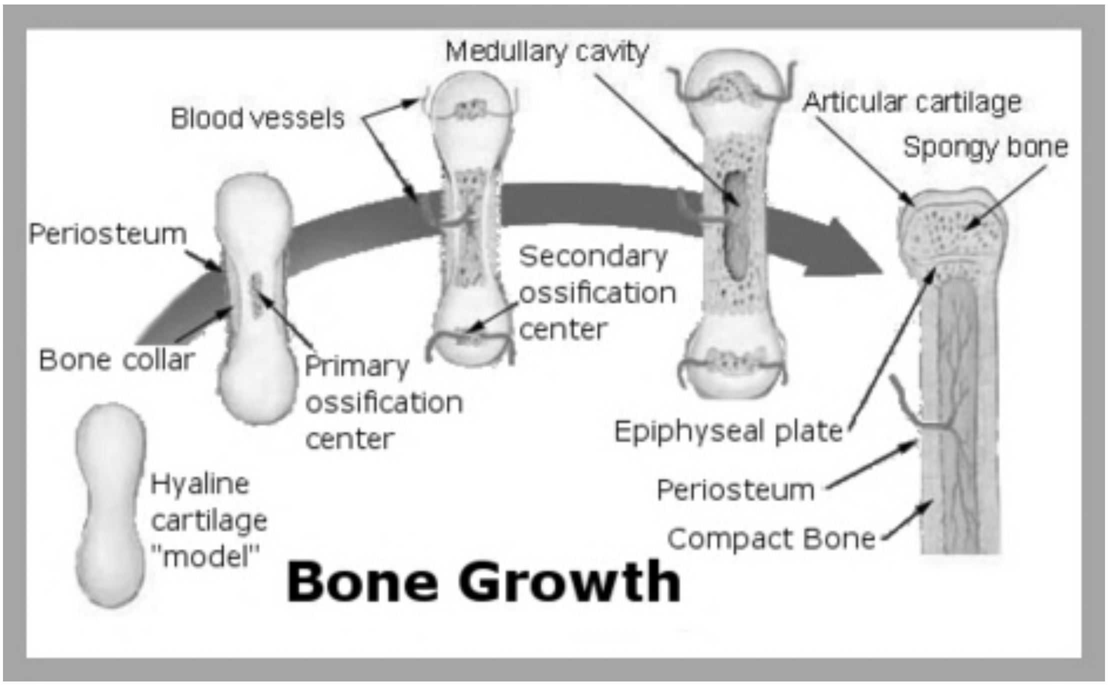
BONE MODELING

The skeleton is developed both pre- and post-birth. The formation of bone happens through two essential processes that create bone tissue, namely *intramembranous* and *endochondral ossification.*

Intramembranous ossification forms the flat bones of the skull and mandible without a cartilaginous predecessor. Bones are formed by direct ossification of collagen (fibrous type 1).

Endochondral ossification is the process responsible for the rudimentary formation of the majority of bones in the horse's skeleton, especially the long bones of the appendicular skeleton and the irregular bones of the vertebral column. Furthermore, this process is also responsible for longitudinal growth as well as healing fractures. To study this process more in-depth, it is easiest to look again at a typical long bone such as the cannon bone - *see picture on the previous page.*

The cannon bone has wide extremities at the ends of the bones called *epiphyses*, a hollow cylinder of compact bone called the *midshaft or diaphysis* and a developmental zone between them called the metaphysis and physis.



The long bone starts to develop in the embryo when the foetus has a pre-formed miniature bone template of *hyaline cartilage.* The material and structural properties of hyaline cartilage are adequate to support the low level of loading in the uterus. However, upon birth, the foal will experience a higher level of loading due to gravitational and muscular forces. Therefore, the hyaline cartilage needs to be gradually converted into a stronger material. This conversion is the process of endochondral ossification, accomplished by vascular invasion, calcification, removal of (calcified) cartilage and replacement with lamellar bone. There are two localised areas of bone formation:

- **Primary centre of ossification →** Diaphysis → the perichondrium initiates ossification of the fibrous tissue and forms a cuff of bone which develops to form the diaphysis.
- **Secondary centre of ossification →** Epiphysis → Primary ossification is followed by further vascular invasion at one or both ends of the developing bone. The bone grows in length at the junction of the epiphyses and diaphysis referred to as *metaphysis*. This is otherwise known as *epiphyseal or growth plate (May-Davis 2017).*

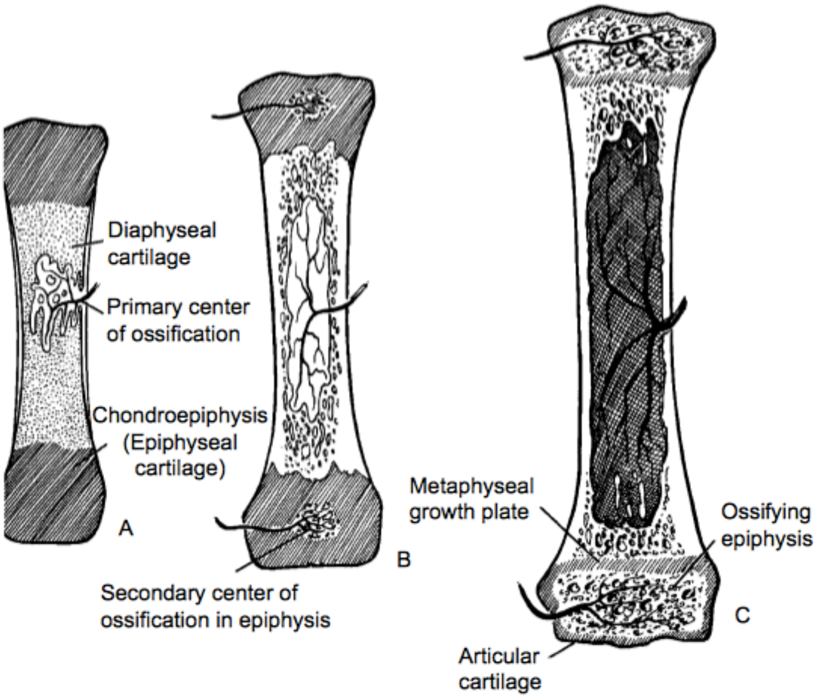


Figure 1. Diagram of ossification of a developing bone

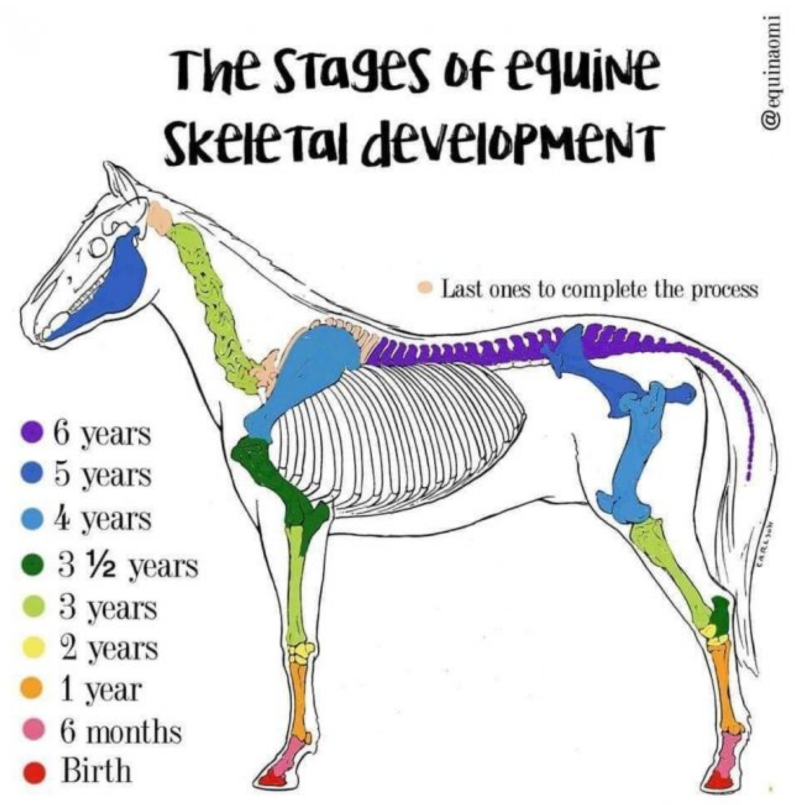
Growth plates close when all the ossified areas have joined after which the bone can no longer grow in length. Different growth plates close at different times in the horse's young live and is influenced by multiple factors such as:

- **Genetics →** The taller the horse the slower the closure of growth plates
- **Nutrition →** The boney materials rely upon nutritional elements to support growth and form strong bones.
- **Gender →** In general, the vertebral column of a gelding closes approximately 6 months later than that of a mare.
- **Parasites →** They can interfere with nutritional uptake and place the body under stress and limiting the ability of the horse to grow.

In general, growth plates close approximately at:

3rd Phalanx	Later stages of gestation
2nd Phalanx	From birth to 6 months of age
1st Phalanx	From 6 months to 1 years of age
3rd Metacarpal	From 8 months to 1,5 years of age
Carpal bones	From 1,5 to 2,5 years of age
Radius, Ulna and Tibia	From 2-3 years of age
Humerus and Femur	From 3-3,5 years of age
Scapula and Pelvis	From 3,5-4 years of age
Tarsal bones	4 years of age
Vertebral column	Up till 6 years of age

In her dissections, renowned pathologist Sharon May-Davis has found variations in these rough estimates. She states that anywhere up to six months could be added to large leg bones and the vertebral column.



BONE REMODELLING

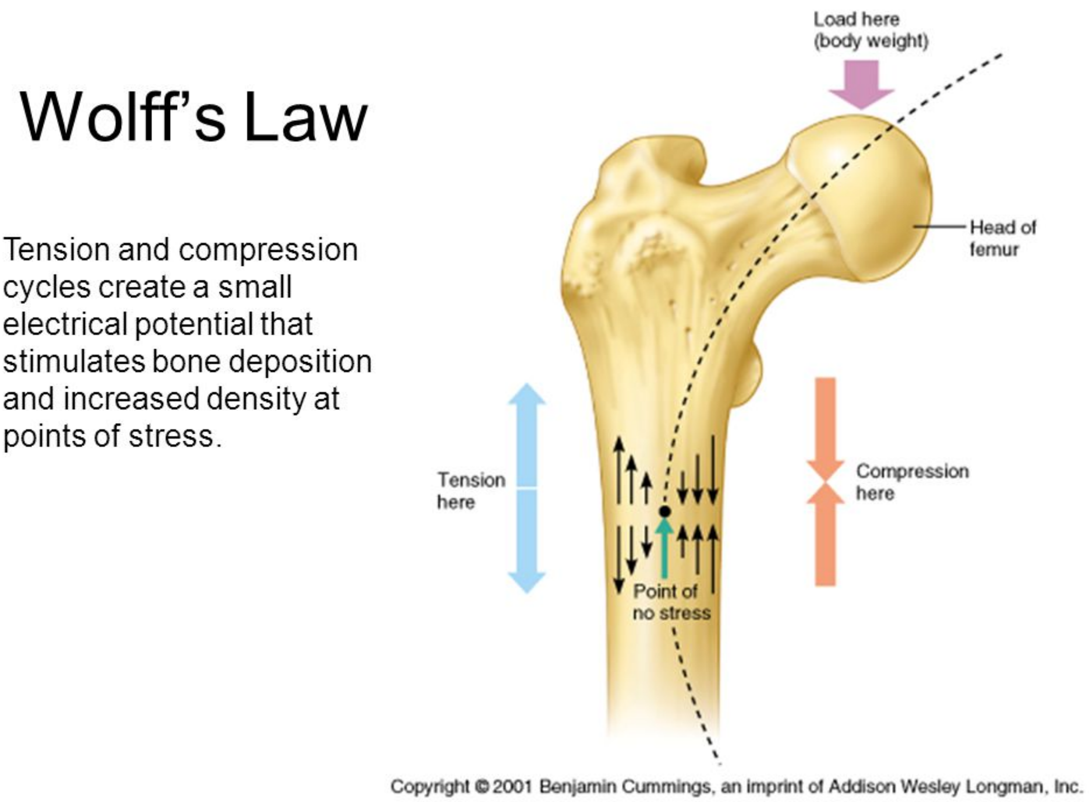
Once the growth plates have closed, bones remain dynamic due to the process of continuous remodelling. Remodelling is a repair process that occurs if a bone is fractured, its surface damaged, or if there is an increase in physical stress. It is argued that under normal circumstances about 5% of the total bone mass is 'turned over' each year by the process of remodelling (Geor 2012). Remodelling is possible due to the strong vascular invasion which holds special bone remodelling cells. The process first involves removal of bone, followed by a reaction of the periosteum to produce new bone. This new bone is eventually mineralized by the addition of calcium and phosphorus, showing that bone remodelling plays a part in remaining a proper balance between calcium and phosphorus.

An over-reaction or trauma of the periosteum can lead to excess formations of bone that may interfere with function and cause pain. An example of this is "ringbone" and shin soreness or 'bucked shins'. It is argued that about 70% of all thoroughbreds in training develop bucked shins to some extent (Westpoint Thoroughbreds 2015).

Pictures adapted from HorseVDM showing bucked shins.

Perhaps because of the magnitude, - ‘’as so many have it should be normal right?’’ - it is often considered as non-serious issue that ‘just happens’’. However, I’d like to argue the opposite as essentially, the remodelling is a response of the horse’s body to excessive stresses it must bear during training: *‘’maintenance of bone content requires further exercise, however, below a critical threshold at which exercise can induce disease’’* (Kawcak 2010).

It has long been recognized that bone size is related to the amount of strain it is subjected. As far back as 1663, Galileo Galilei already described a positive relationship between body weight and bone size. In the 19th century Dr. Julius Wolff build on these principles by stating that bone will adapt in response to the loads it is placed under. He developed mathematical laws describing the relationship between mechanical load, or strain on (an area of) bone and the changes in bone structure and strength.



Load (F) : The external force placed on the bone

Strain : The proportional change in the bone's dimensions

Stress : The internal forces resisting the change in dimension caused by the load

Therefore, increased load will result in an increase of bone mass whereas a decreased load will result in a reduction in bone mass. This enhances the understanding of bone as a dynamic organic that is ever changing and adapting to its local environment.

These are important concepts when considering the effects of training and performance on bone as appropriate training should stimulate bone modelling, improve skeletal strength, and, in theory, reduce the probability of exercise-associated skeletal injuries.

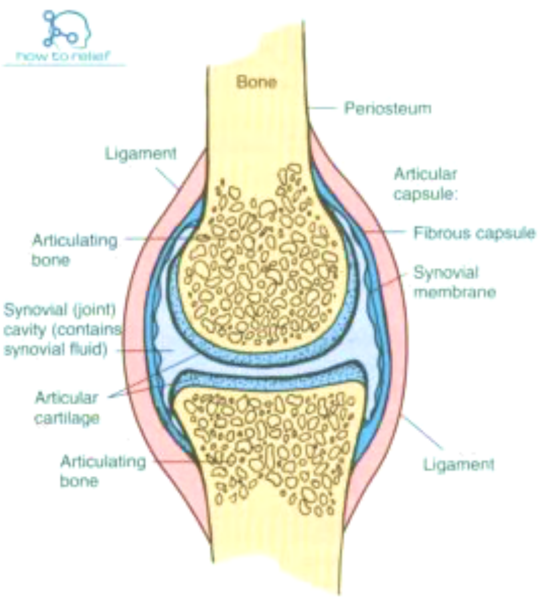
JOINTS

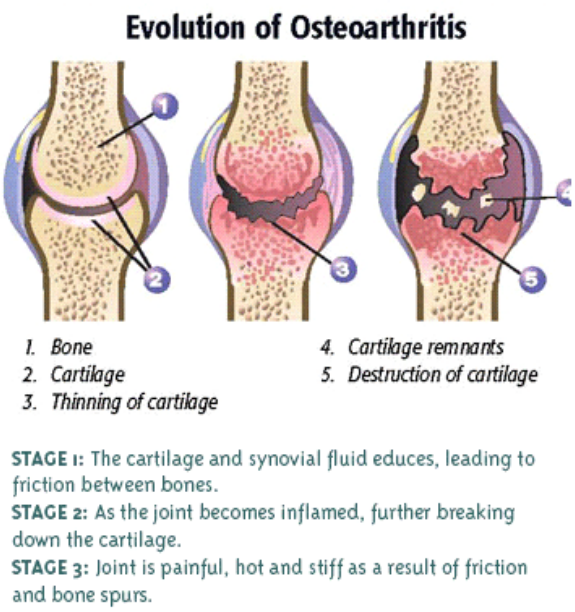
A joint or articulation is the connection made between bones in the body which link the skeletal system into a functional and holistic whole. They are designed to allow for different degrees and types of movement. Some joints, such as the carpus, elbow, and shoulder, are self-lubricating, almost frictionless, and are able to withstand compression and maintain heavy loads while still executing smooth and precise movements.

Other joints such as sutures between the bones of the skull permit very little movement (only during birth) in order to protect the brain and the sense organs.

Joints are primarily classified according to their structure and the material that unites them:

- **Fibrous joint →** these are fixed joints where bones are connected by a dense fibrous material rich in collagen fibres. ROM is limited. E.g. splint bones and teeth.
- **Cartilaginous joint →** the joints have no cavity and bones are united by cartilage. ROM between bones is more than a fibrous joint but less than the highly mobile synovial joint. e.g. growth plates and vertebrae (intervertebral discs).
- **Synovial joint→** these joins bones with a fibrous joint capsule that is continuous with the periosteum the joined bones, constitutes the outer boundary of a synovial cavity, and surrounds the bones' articulating surfaces. The synovial cavity/joint is filled with synovial fluid. The joint capsule is made up of an outer layer, the articular capsule, which keeps the bones together structurally, and an inner layer, the synovial membrane, which seals in the synovial fluid. These joints are mostly found in the limbs or regions with a greater ROM. e.g. fetlock, knee, elbow and cervical vertebrae etc.





JOINT MOVEMENT

A healthy joint can exhibit the following movements: **-**

- **Gliding →** One articular surface glides over the other articular surface. E.g. movement between the articular facet of vertebrae; carpals.
- **Flexion →** Closing the angle of the joint. E.g. carpus, elbow, intervertebral joints
- **Extension →** Opening the angle of the joint. E.g. carpus, elbow, intervertebral joints
- **Adduction →** Moving toward the midline of the body. E.g. shoulder joint; crossing over the legs; half pass
- **Abduction →** Moving away from the midline of the body. E.g. shoulder joint; half pass; lifting the limb to the side
- **Rotation →** Twisting movement around a longitudinal axis. E.g. shaking the head; twisting the vertebrae
- **Circumduction →** a circular movement that consists in part of all the previous actions except for rotation. E.g. a horse that plaits or paddles.

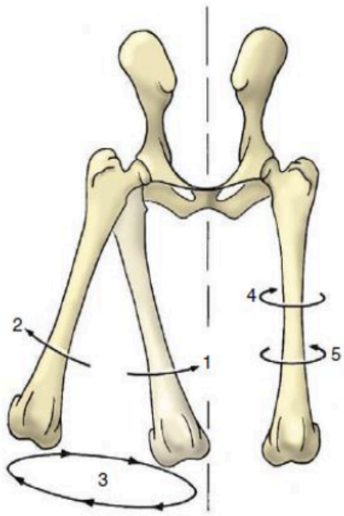


Figure 1–23 Limb movements illustrated by the femurs of the dog, cranial view. *1,* Adduction; *2,* abduction; *3,* circumduction; *4,* inward rotation; *5,* outward rotation.

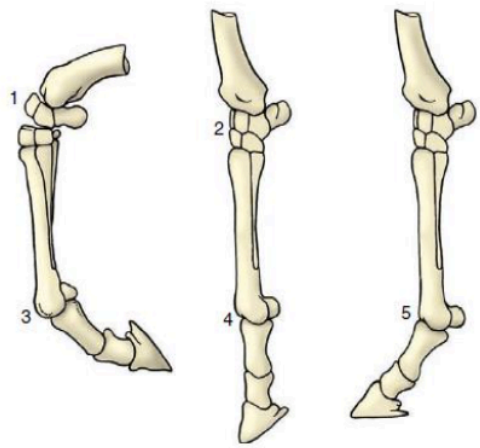


Figure 1–24 Flexion, extension, and overextension illustrated by the distal part of the horse's forelimb. *1,* Flexed carpal joint; *2,* extended carpal joint; *3,* flexed fetlock joint; *4,* extended fetlock joint; *5,* overextended fetlock joint.

MUSCLES

The horse is built for movement, from the up and down motion of a trot, to a flowing canter. Movement requires muscles of which three types can be found in a horse:

- **Striated muscles →** skeletal muscles that move the bone. These muscles are controlled by the central nervous system, due to which muscle contractions occur involuntarily (Ettl 2017)
- **Cardiac muscles →** muscles of the heart. These muscles occupy a special position due to its hollow structure. They have their own electrical stimulation system and cannot be voluntarily controlled.
- **Smooth muscles →** muscles of organs, digestive system and blood vessels. These muscles are controlled by the automatic nervous system and therefore cannot be voluntarily controlled.

SKELETAL MUSCLES

The skeleton is the boney framework of the horse. Skeletal muscles attach to and move the bones. There are more than 700 skeletal muscles which makes up for half of the dynamic musculoskeletal system. They are mainly designed to:

- **Stabilize the joints**
- **Maintain posture**
- **Produce movement**
- **Generate heat via shivering**
- **Serve as a pathway for nerve and blood vessels**

Skeletal muscles are usually arranged in pairs and act in conjunction with other muscles. When muscles cause a limb to move through the joint's range of motion, they usually act in the following cooperating groups:

- **Antagonistic relationship →** Muscles opposing each other called. Within an antagonistic pair, there is one muscle to flex a joint while the other extends it. This means while one muscle relaxes, the other will contract so that the joint operates properly. The agonistic muscles are the ones activated and causing an action. Agonists are also referred to as *prime movers* since they are the muscles primarily responsible for generating the movement. The antagonistic muscles on the other hand act in opposition to the movement generated by the agonists and responsible for returning a limb to its initial position. A few examples: contracting biceps Brachii (agonist), opposing triceps (antagonist); contracting Quadriceps, opposing Hamstrings; contracting Flexors, opposing Extensors. The muscles or tendons attached are called a **flexor unit**, if the joint is caused flexion and **extensor unit** if the joint is caused extension.

- **Synergetic relationship →** Muscles (assisting in) producing the same movement as the agonists. Synergists are also referred to as neutralizers because they help cancel out extra movement from the agonists to make sure that the energy generated works within the desired plane of motion. Fixator muscles on the other hand stabilises the origin of the agonist and the joint that the origin spans - moves over - in order to help the agonist function most effectively. An example: Biceps Femoris (hamstrings) partners with Semitendinosus and Semimembranosus to flex and adduct the stifle. For the stifle to flex while not rotating in either direction, all three muscles contract to stabilize the stifle while it moves in the desired way.

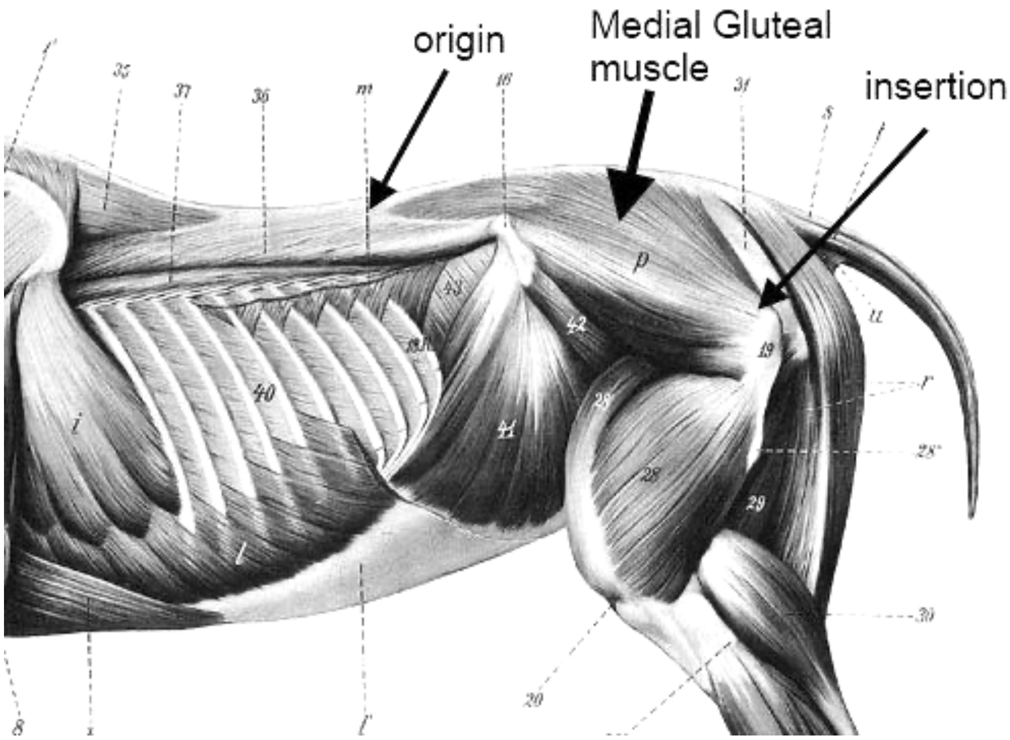
In good movement, muscle groupings work in harmony and balance. Poor movement over stresses – hypertrophies - some muscle groups and underutilizes – atrophies - others resulting in poor posture and incorrect unbalanced muscle development, affecting the joints of the horse.

ATTACHMENTS: ORIGINS AND INSERTIONS

A muscle can have one or more origins and insertions. In general, origins are attached to the least movable (stationary) bone whilst insertions are attached to the more movable bone. A muscle can have one or more origins and insertions.

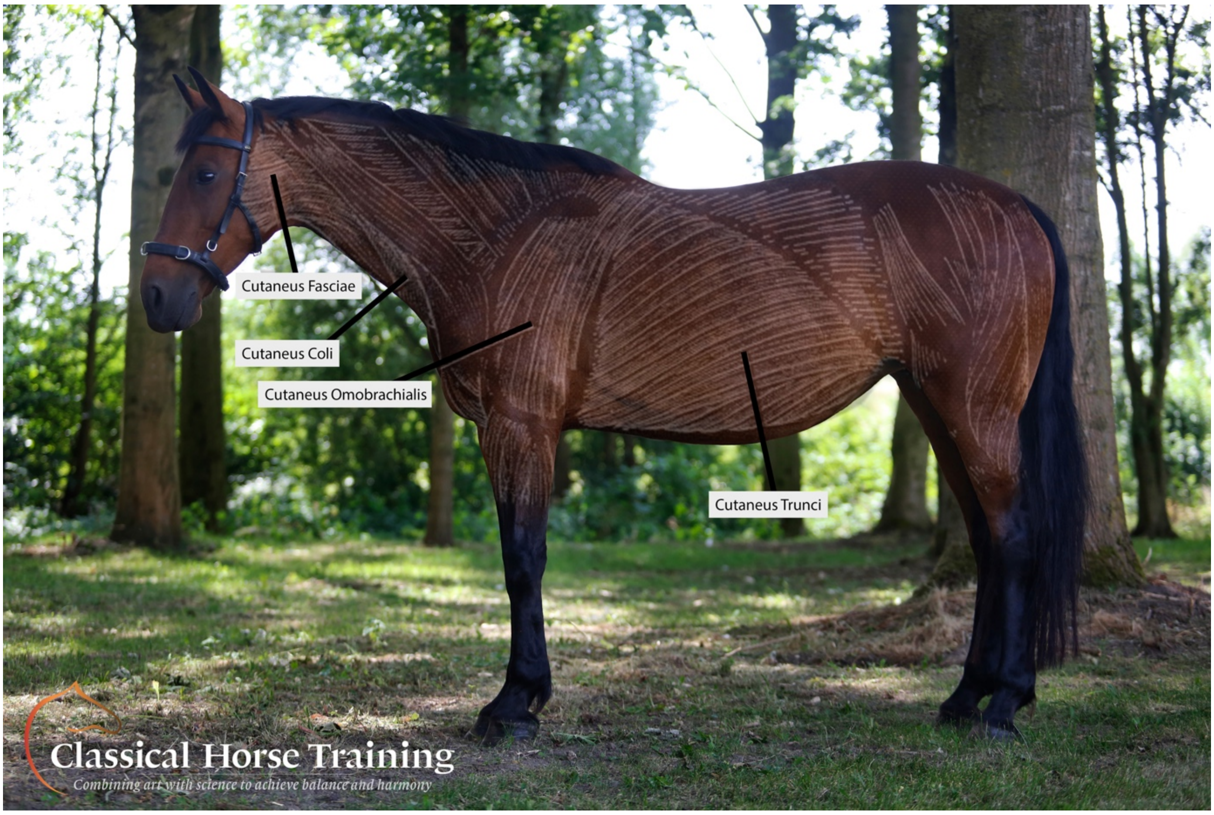
As a muscle primarily contracts, it almost always brings the movable insertion closer to the least movable origin causing one or both bones to move, articulating the joints. Muscular contraction is therefore transmitted via the belly of the muscle to the point of attachment.

An example: *'' the middle gluteal in the hindquarter originates from the ilium of the pelvis and inserts onto the summit of the greater trochanter. Upon contraction the hip joint is extended. However, in the case of the extensor carpi radialis, its origin attaches proximally to the Humerus and inserts distally into the dorsal proximal tubercle of third metacarpal. Upon contraction - the elbow is flexed and the knee extended''* (May-Davis 2017).



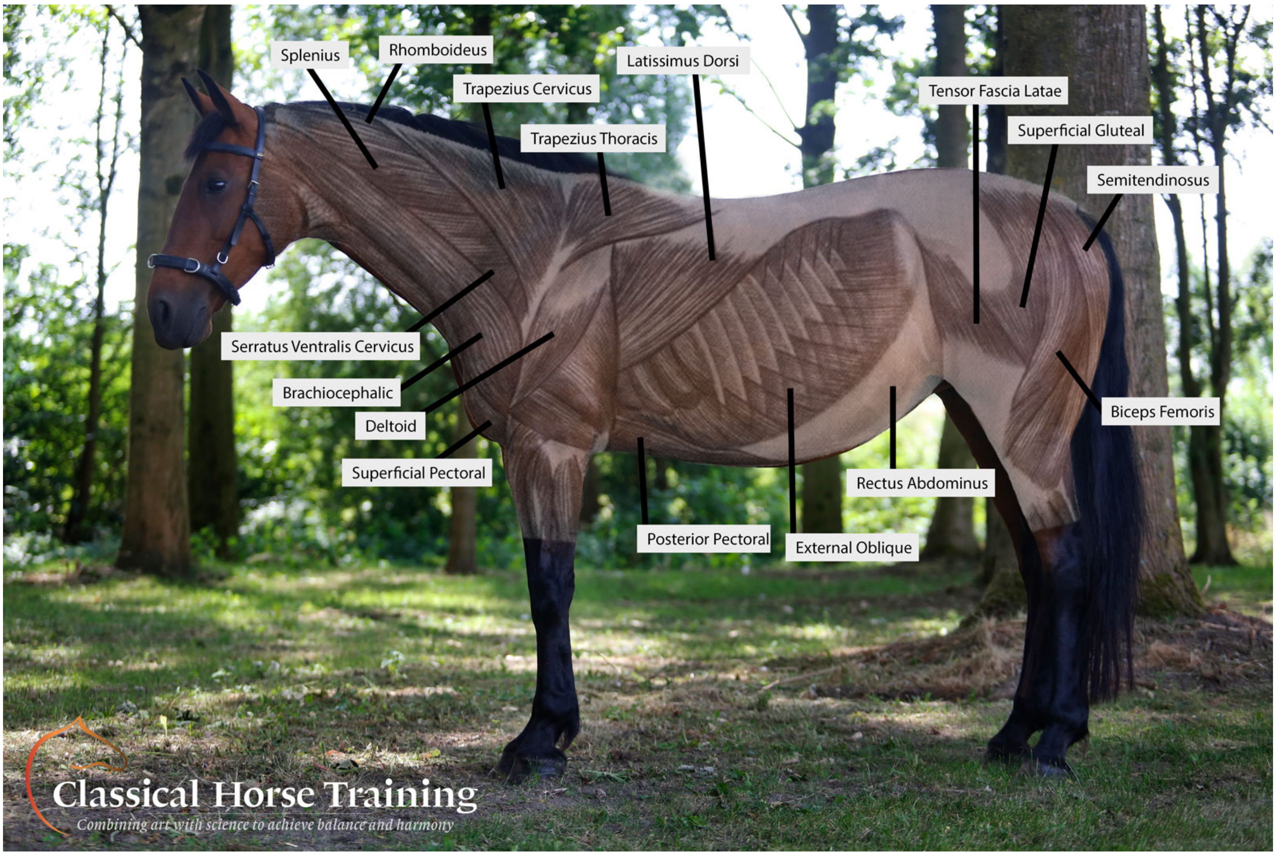
MUSCLE LAYERS

In regard to muscle layers, it becomes hard to differentiate between the layers. However, *''one thing is for certain and that is the most external or superficial layer belong to the cutaneous group. These muscles are often activated when a fly or annoying insect lands on the horse.''*- May-Davis 2017

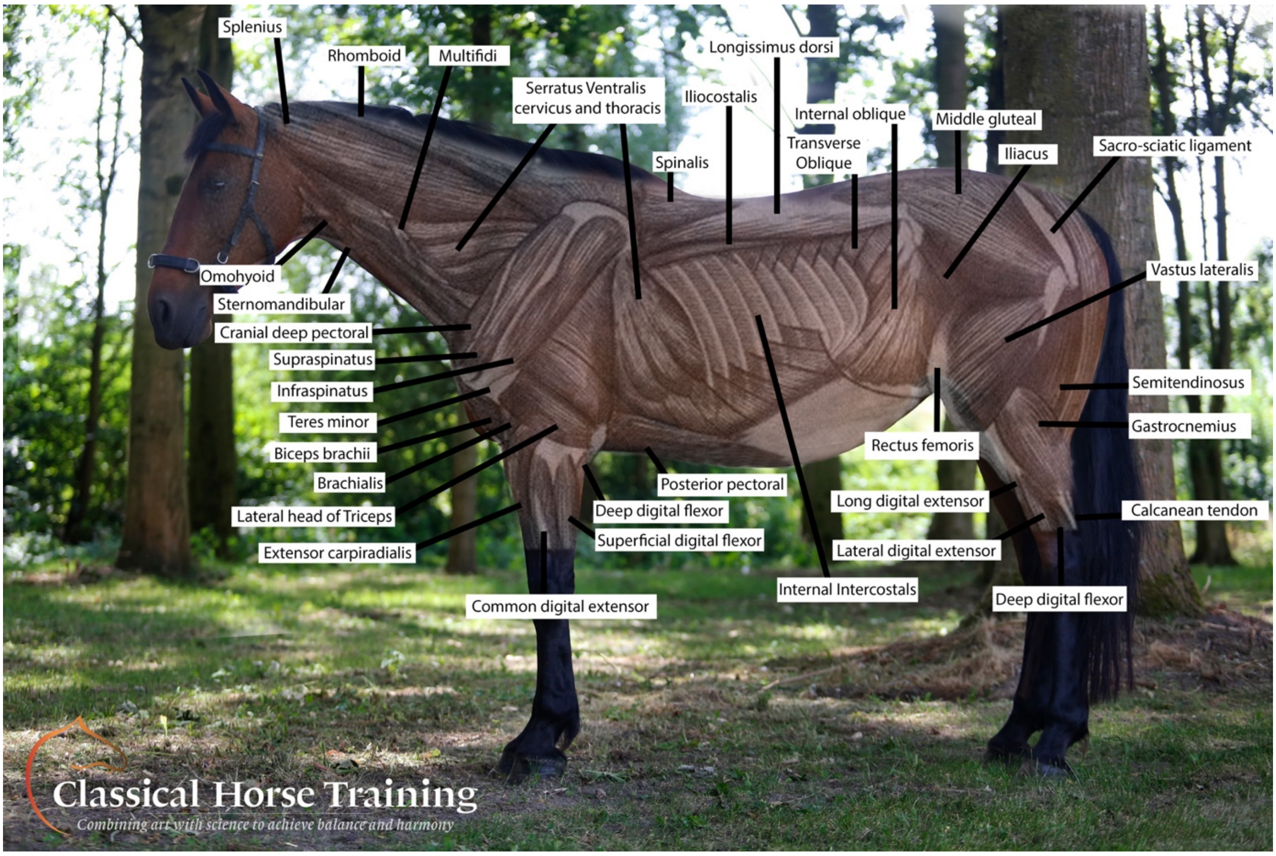


<u>Note:</u> Cutaneous muscles often appear as lines underneath the skin with a slightly raised edge and are sometimes mistakenly referred to as an unidentified inflammation. This is mostly due to someone's inability to explain what they are seeing or feeling. But this is not the case, every horse is different and these lines are like identification markers creating their own personal signature. See the corresponding video for more explanation about cutaneous linings.

Below the cutaneous group we find the common superficial muscles.



The deep muscles are, as the name suggests, located below the superficial muscles.



MUSCLE CONTRACTIONS

Skeletal muscles consist of a number of muscle bundles made of muscle fibres – or in fancy terms fascicles. These fibres have bundles of myofibrils, which run parallel to each other. Contraction therefore involves motor function. The muscles are controlled by motor neurons that stimulate contraction of the muscle fibres. They are enabled to contract because of the proteins actin and myosin.

The neurons receive signals from the brain and stimulate contraction of all the muscle fibres in that particular motor unit. A motor unit is made up of a motor neuron and the skeletal muscle fibres innervated by that motor neuron to contract. This chemical synapse is referred to as a neuromuscular junction.

Apart from nerve impulses, outside stimuli can also act on muscles. These can include:

- **Mechanical stimuli** → pulling, pushing or an impact
- **Chemical effects** → administration of drugs, acids, alcohol etc.
- **Thermal effects** → Extremely hot or cold temperatures can damage muscle fibres

Although being elastic, muscle fibres can tear if the muscle is suddenly stretched very heavily. A warmed-up muscle that is well-supplied with blood is more elastic than a cold muscle. To prevent injuries by overstretching, a good warm-up routing is essential for any form of therapy as well as training.

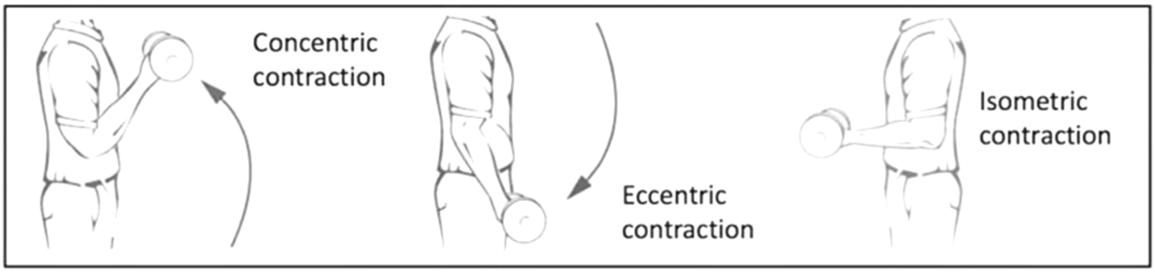
The contraction of a muscle does not necessarily imply that the muscle shortens; it only means that tension has been generated. The energy produced by muscle contraction consists of 25% kinetic energy and 75% heat energy (Ettl 2017).

Muscles can contract in the following ways:

- **Concentric** → Muscle shortens generating tension.
  Example: piaffe with bending of the hind legs or going to lay down.
- **Eccentric** → Muscle lengthens as it generates tension. Eccentric contractions are believed to be the most powerful contractions and thus have nothing to

do with relaxation: *''Muscles working eccentrically can absorb up to 15 times more energy than during concentric contractions.''* - Payne et al. 2004

- **Isometric** → No change in muscle length as it generates tension. Often observed when the horse is trying to stabilize during transport
- **Ballistic** → Ability to contract with momentum allowing fast movements to produce a larger range of motion. Example: Ballotade and croupade.



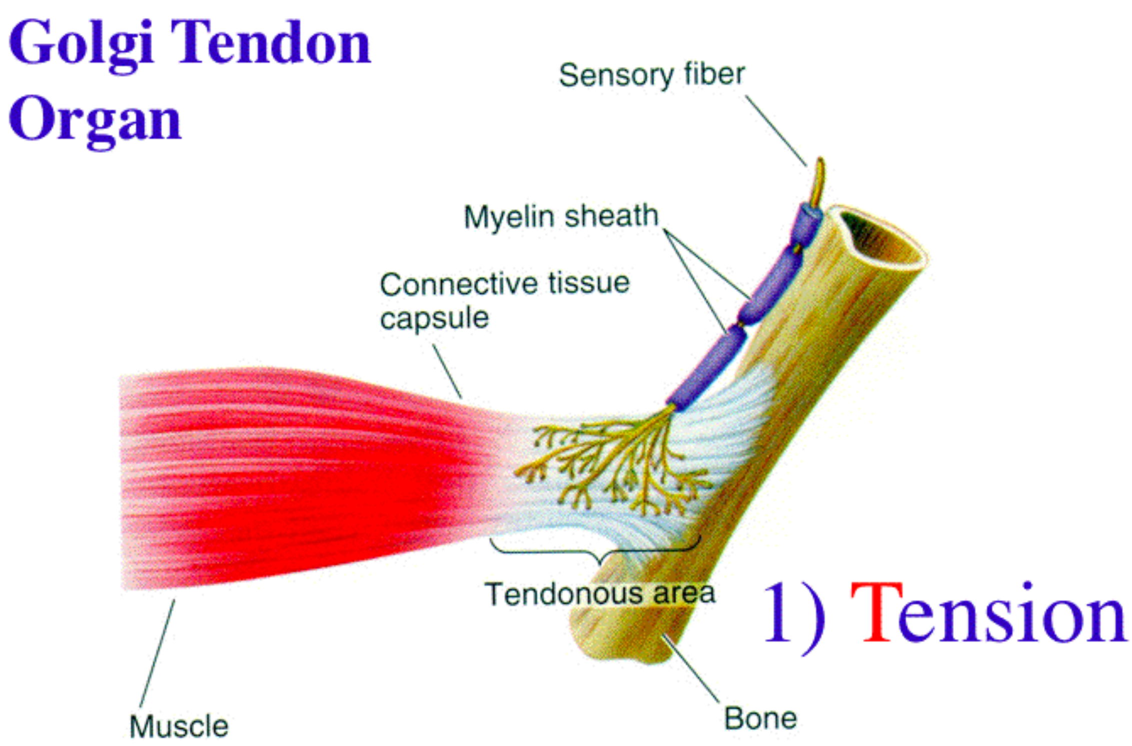
A Dutch Konik foal displaying both closed (right hind) and open (left hind) eccentric muscle contractions.

While muscle contractions describe tension producing movement, muscle toning describes tension in the muscles at rest. Even when a muscle is not contracting, a small number of its motor units are involuntarily activated to produce a sustained contraction of the muscle fibres.

The process gives rise to muscle tone. To sustain muscle tone, small groups of motor units are alternately active and inactive in a constantly shifting pattern. Muscle tone keeps skeletal muscles firm, but it does not result in a contraction strong enough to produce movement.

GOLGI TENDON ORGAN

The Golgi tendon organ is a proprioceptive sensory receptor organ that senses changes in muscle tension. It controls muscle contraction and therefore the timing of the swing and stance phases of the limbs in movement. It also provides feedback to the spinal cord and cerebellum from the musculo-tendinous junction.



The Golgi Tendon Organ lies at the origins and insertion of skeletal muscle fibres into the tendons providing the sensory component of the Golgi tendon reflex. It is composed of strands of collagen that connect the muscle fibres into the tendon and is innervated by sensory nerves creating a spiral around the collagen strands. This unit is called the neuro - tendinous spindle which is enclosed by a fibrous capsule (Butler 2017).

MUSCLE ACTIONS

Muscle actions are movements caused by muscle contractions. Muscles actions can be:

- **Flexion** → Forward movement decreasing the angle between two bones (bending). Examples: coiling of the loins
- **Extension** → Backward movement increasing the angle between two bone (straightening a bend). Examples: bring leg back; Hollowing the back
  NOTE: Skeletal muscles do not extend below the knee or hocks!
- **Abduction** → Lateral movement away from the body's midline / centre of mass. Example: Sideways movements; Lifting the leg to the side
- **Adduction** → Lateral movement towards the body's midline / centre of mass Example: Laterals (half pass); Crossing one leg in front of the other
- **Rotation** → Twisting movement around longitudinal axis. Example: shaking the head

Adduction in the half pass in walk

TENDONS & LIGAMENTS

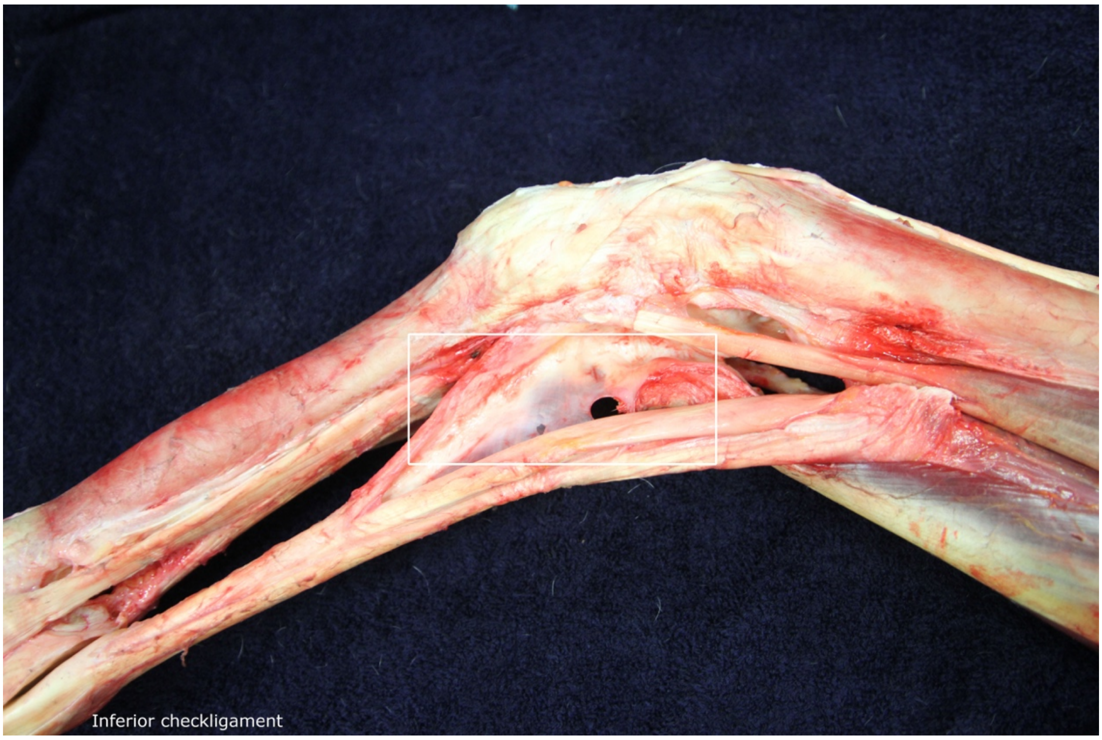
Skeletal muscles are covered by fascia and rely on associated connective tissue to assist in function.

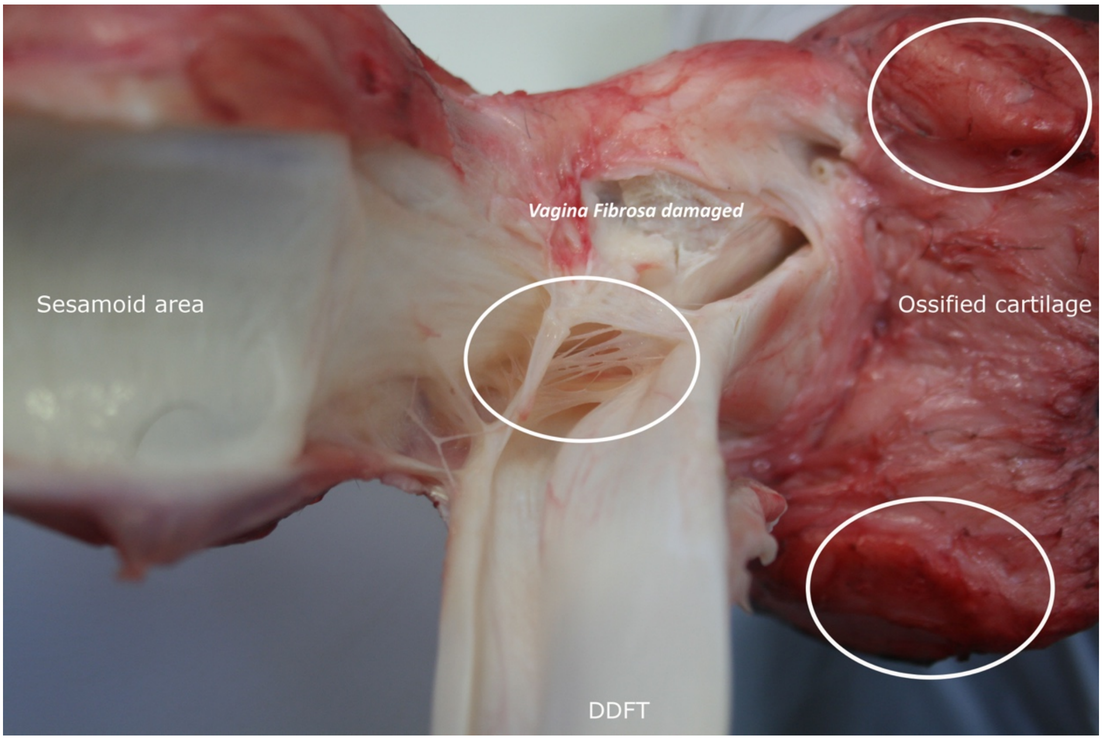
Tendons attach muscle to bone and sometimes to another muscle or cartilage. When a skeletal muscle contract, it pulls on a tendon. Tendons assist in acting on the bone to bring it closer to the point of contraction and can articulate two or more bones depending on their site of attachment (May-Davis 2017). Tendons come in various shapes and have little elasticity. Notable exceptions are the Middle Gluteal Tongue, Cranial portion of Biceps Femoris and Lacertus fibrosis.

Furthermore, tendons are poorly supplied with blood and thus take a long time to heal or train.


More dissecting the out Deep and the Superfiscial digital flexor tendon

Ligaments attach 'bone to bone' and in some cases ‘tendon to bone’. Unlike tendons, they’re usually flat. They’re highly inelastic and are designed to stabilize the joints and prevent abnormal joint movement. For example: collateral ligaments. Exceptions are however, the Nuchal, Suspensory and Inferior/ Superior check ligaments.





Below: the Vagina Fibrosa is a 'check' ligament that hardly appears in any anatomy textbooks. It protects the Deep Digital Flexor Tendon from excessive movement. When it is torn or inflamed, the horse often gets problems in the fetlock area such as hypermobility or suspensory ligament desmites.

Both ligaments and tendons are accredited to have a certain recoil system upon movement that creates 'spring' in the horse's movement:

> *''Elastic structures, like tendons and ligaments, store energy when elongated. This energy is released when they return to their normal length''*
>
> - Meershoek en van den Bogert (1996)

Although recoil indeed is a phenomom, please remember that in reality it is actually very little as most tendons and ligaments are not super elastic and in fact quite rigid.

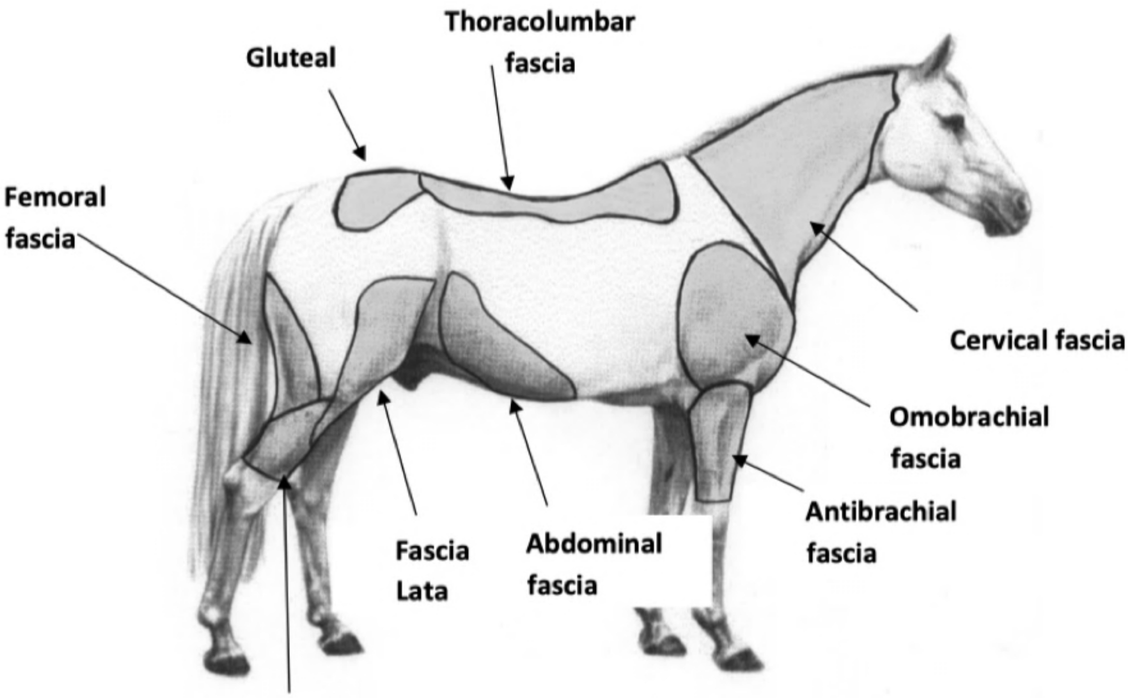
I will not elaborate on tendons and ligaments too much as this will be more of a topic for more advanced courses in the future.

FASCIA

Until recently, fascia remained largely unexplored in both humans and horses. Luckily, it is getting more and more recognized as an important organ in the horse's. body. Now, the definition of fascia is where it gets a little bit tricky as there are many different descriptions to be found. In general, it is considered as a multidimensional dynamic and static web of collagenous based connective soft tissue that wraps around 'everything' in the body.

You might have also heard about the term 'Myofascia'. All this means is muscle (myo-) and its surrounding web of connecting tissue (-fascia). Myofascia thus links muscular and non-muscular tissue. Through this relationship it influences muscle mechanics and is involved in energy distribution recoil and shock absorption as well as posture and biomechanics. When a practitioner is working on fascia, they most commonly try to loosen the connections between the muscles so that the horse can move (more) freely.

Located beneath the skin, fascia is primary composed of collagen and attaches, stabilizes, encloses and separates muscles and other internal organs. By doing so it defines and influences the entire body.



Like ligaments, aponeuroses and tendons, fascia also contains closely packed bundles of collagen fibres oriented in a wavy pattern parallel to the direction of pull. Consequently, it is elastic in structure with enormous tensile strength ánd contractile properties. Because it has the ability to contract on its own it can store and release elastic potential energy. However, in some cases it can also lead to muscles becoming stuck to other muscles and structures, therefore decreasing the ability of the muscles to contract and lengthen correctly.

In a normal state, fascia can be like a gelatinous substance, but when damaged it can become rigid and can easily form fibrotic bands. Fascial restrictions can have far reaching effects as nerves and blood vessels get compromised. Furthermore it can also impede joint function.

Fascia is also frequently innervated by sensory nerve endings and therefore plays a huge role in proprioception and posture. When pressured or stretched, it gives of an electromagnetic signal and with its richly endowed nerve endings, it can produce a nasty burning pain when damaged.

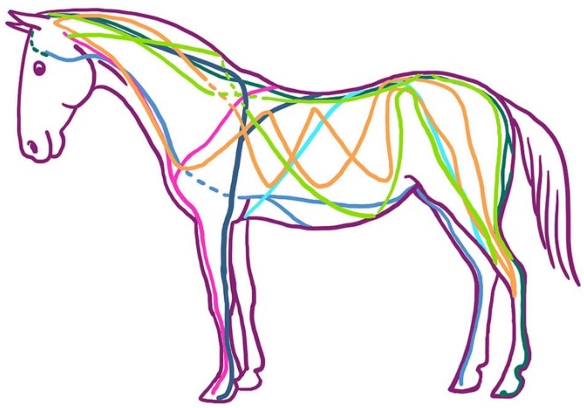
Although fascia can often not be discerned, we can roughly qualify 3 layers of fascia:

- **Superficial fascia →** a loose collagenous connective tissue directly under the skin. Example: Cutaneous fascia, Thoracolumbar fascia and Gluteal fascia. Superficial fascia can interface with deep fascia, at which point it becomes less loose and more tensile in structure. Because of this connection, any trauma or restriction to the superficial fascia can influence the deeper musculature it encompasses.
- **Deep fascia →** A dense collagenous connective tissue below the superficial layer. It separates certain muscles or their parts and may provide (in part), an origin or insertion for that muscle. Example: the Superficial gluteal and the Tensor Fascia Latae originate from the Tubercoxae, however, they also originate in part from an intermuscular septum formed between these two muscles, which is actually deep fascia. Also the duramater can be considered

as a deep fascia as it is a dense fibrous tube surrounding the brain and spinal cord.

- **Subserous fascia →** Suspends the organs within their cavities and wraps them in connective tissue layers. Subserous fascia is less extensible than superficial fascia. Due to its suspensory role of the organs, it needs to maintain its tone rather consistently. If it is too lax, it contributes to organ prolapse, yet if it is hypertonic, it restricts proper organ motility (Paoletti 2006).

In 2015, Danish researchers Vibeke Sødring Elbrønd and Rikke Mark Schultz published a paper on myofascial kinetic lines in horses. The outcomes of this research were picked up quickly and many diagrams of these lines have been published. However, I must say that upon dissections, I have never seen these lines as described in these diagrams. As such, I personally feel that more research is needed and I advise you to take come caution into interpreting these lines.



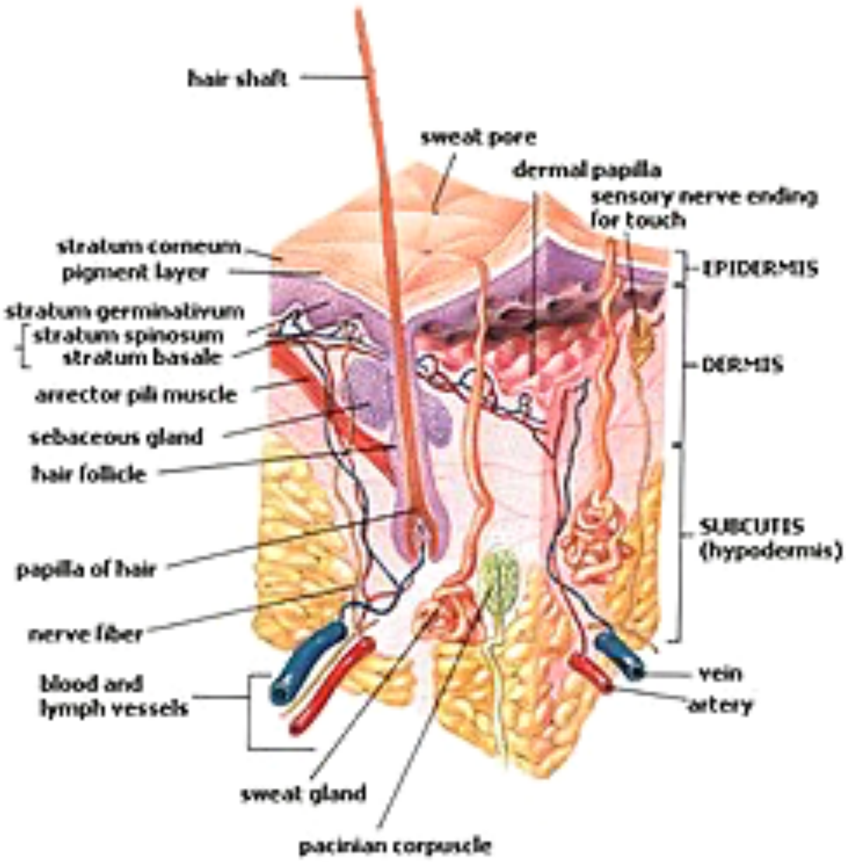
So called myofascial kinetic lines. Although I strongly believe in the importance of fascia and the interconnection it provides, I am a bit unsure about these so commonly presented lines as I haven't been able to differentiate them upon dissections.

SKIN

Skin is the biggest dynamic organ in the horse's body with the ability of multidirectional stretch and compression and a low friction gliding movement. The skin has multiple functions:

- **Regulating temperature** → through shivering
- **Providing a protective barrier** → against the environment
- **Providing sense of touch and physiology** → live sensory feedback via somatosensory and autonomic neurons.

The skin contains a complex microvascular system and neurovascular network. There is a close integrated relationship with the underlying fascial endoskeleton formed via retinacular ligaments, blood vessels, nerves and lymphatic vessels.



Skin is made up of an amorphous matrix, fibrillar collagen, sulphated proteoglycans, glycoprotein, glycosaminoglycans (GAGS) and Hyaluronic acid (HA). They carry a negative charge allowing them to bind up to 3000 x their own volume of water influencing dermal and hypodermal volume and compressibility. Skin is affected by race, sex, age, site, scars and obesity.

Skin can be roughly divided into 3 layers:

- **Epidermis** → outer layer
- **Dermis** → middle layer
- **Hyperdermis** → deepest layer

The epidermis provides a protection barrier from foreign substances. It includes multiple types of cells such as keratinocytes, melanocytes, Langerhans- and Merkel cells.

Keratinocytes provide a protective layer that is constantly being renewed in a process called keratinization. In this process, new skin cells are created near the base of the epidermis and migrate upwards. This produces a compact layer of dead cells on the skin surface. This layer keeps in fluids, electrolytes, and nutrients, while keeping out infectious or noxious agents. The top layer of dead skin cells are continuously shed and replaced by cells from lower layers. The rate of cell replacement is affected by nutrition, hormones, tissue factors, immune cells in the skin, and genetics. Disease and inflammation can also change normal cell growth and keratinization.

Melanocytes produces the skin and hair colouring – pigment – called melanin at the base of the epidermis , the outer root sheath of hairs, and the ducts of the sebaceous and sweat glands. Production of melanin is controlled by both hormones and the genes received from parents. Melanin helps protect the cells from the damaging rays of the sun.

Langerhans cells are part of the immune system. These cells are damaged when exposed to excessive ultraviolet light and glucocorticoids (anti-inflammatory drugs). Langerhans cells play an important role in the skin's response to foreign substances and contribute to such things as the development of rashes when an animal is exposed to irritating materials.

Merkel cells are specialized cells associated with the sensory organs in the skin.
In particular, Merkel cells help provide animals with sensory information from whiskers and the deep skin areas called *tylotrich* pads (Moriello et. All 2015).

The hypodermis serves as a protective barrier between the epidermis and the dermis.

The dermis is the thick layer containing nerve ends, hair follicles, sebaceous (oil) and sweat glands, blood and lymphatic vessels. It supports and nourishes the epidermis and skin appendages. It secrets collagen fibres that give the skin elasticity.

These layers are divided by loose connective tissue regions allowing gliding. Therefore, there is a close interaction with the underlying fascial endoskeleton:

> ''*The skin acts as an envelope to the body and is closely integrated to the underlying fascial endoskeleton through retinacular ligaments, blood vessels nerves and lymphatics. Only when skin is diseased, scarred or aged do we appreciate how important this feature is to daily activity.* '' - Schierling 2015

The fascial endoskeleton is important in determining the limits of skin movement – the gliding of skin over muscle contraction. The connections between fascia through to skin act as a continuum for finite movement. When the fascial system degenerates in aging, obesity and disease we can see a change in skin movement – for example wrinkles.

NERVOUS SYSTEMS

The neurology of the horse is a highly complex single unit that regulates all bodily functions and should therefore, although difficult, be the centre of any training method: *''Guiding the horse's brain towards the most efficient body coordination demands understanding and respect for reality.''*

The regulation of body functions and movement is organized by the Central Nervous System (CNS) and the Peripheral Nervous System (PNS). Below you can find a schematic outline of all divisions:

Central Nervous System CNS

Peripheral Nervous System PNS

Somatic Nervous System SNS

Automatic Nervous System ANS

Sympathetic Nervous System SNS

Parasympathetic Nervous System PNS

The Central Nervous System can be considered the information highway or the 'computer' of the horse and consists of the brain and spinal cord. The Peripheral Nervous System governs the neurons located outside the CNS and consists of two type of nerves that communicate with the CNS:

- **Sensory Nerves** → carry information from the body parts to the CNS
- **Motor Nerves** → carry information from the CNS to the body parts

The PNS can further be divided into two divisions which are designated into specific regions:

- **Somatic Nervous System (SNS)** → regulates organs and tissue (except the gut) andadministers control of sense organs and most skeletal muscles
- **Automatic Nervous System (ANS)** → regulates the involuntary systems such as the heart, respiratory and digestive systems as well as the functioning of glands. The ANS can finally be divided into the sympathetic and parasympathetic nervous systems which usually supply the same organ, but trigger different responses.

The **sympathetic nervous system** governs the 'fight' of 'flight' reaction in a horse. It alerts the horse to danger, stress or any other unpleasant circumstances, sending messages to the CNS to increase heart rate, blood pressure etc. to get the horse ready for fight or flight.

The **parasympathetic nervous system** on the other hand governs the 'rest, relaxed and digest' reaction in a horse, which increases blood flow, healthier immune system and healing.

Many horses suffer to ANS imbalance to some extent. They are often considered nervous, inconsistent or even naughty. The lesser trainers blame the horse, saying it has an attitude problem, instead of realizing there may be a fundamental physical problem. The best of trainers will recognize this underlying issue and wait until the balance is restored and the horse starts to settle before attempting to work with a horse exhibiting these symptoms. Horses with a sympathetic nervous system dominance often display an overly acidic gut and may not be able to gain or hold condition and/or may lack interest in feed. However, signs can be subtler as some horse internalise their anxiety. See a short overview below:

	Parasympathetic Nervous System	**Sympathetic Nervous System**
Increases	Digestions	Heart rate
	Intestinal mobility	Blood pressure
	Fuel storage	Body temperature
	Insulin activity	Blood to skeletal muscle
	Resistance to infection	Stimulation sweat glands
	Rest and recuperation	Bronchodilation

The nervous systems react to a certain set of stimuli via electrical impulses or 'messages'. These messages can be initiated from internal organs or in response to an environmental influence. They are sent to the brain (CNS) for analysis and the return message is what initiates the response. An example: A fly lands on a horse and it becomes irritated by its presence. The brain receives the message and sends out an instruction to respond with one or a number of actions to remove the fly such as flicking the tail, twitching the skin or scratching (May-Davis 2017).

MUSCLE MEMORY

The action of muscles is also guided by neural processes and as such, in essence, training a horse is working with its brain:

> *"Although certain skills, might require the strengthening of certain muscles, the processes that are important for learning and memory of new skills occur mainly in the brain, not in the muscles."* – Johnstone 2019

This allows the horse to develop so called muscle memory. Muscle memory is a common concept within human artistry: ''Musicians must practice until muscle memory sets in, until the brain is free to forget, but the body still clearly remembers.'' So how does this relate to horse training?

First of all, the name is somewhat a misnomer as there is no literal memory in the muscles and the brain hasn't forgotten[2] . A better name might be subconscious memory as the information is stored in the brain, but is most readily accessible – or only accessible – by non-conscious means:

> *''These fast and efficient movements resulting from practice are procedural memories stored in areas of the brain that operate outside of conscious awareness.''*- Foster 2019

Thus, although difficult to document, the term muscle memory refers to a learned component of training in which patterns of specific muscle actions are acquired and fixed. As such, muscle memory involves consolidating a specific motor task through repetition.

When teaching the horse a new motor skill or sequence, the first attempts require conscious

[2] *The octopus is the only creature known to have a brain in their limbs and thus have direct 'muscle memory'.*

attention and sensory-motor feedback about the movements that lead to a desired result. This feedback goes via a pathway of both gymnastic and cybernetic muscles. Gymnastic muscles are typically long and poorly innervated muscles that mainly produce movement. Cybernetic muscles on the other hand are usually shorter postural muscles located close to the vertebral column and are rich in nerve innervation . It is these muscles that have a large capacity to quickly 'remember' once a behaviour is repeated multiple times. In doing so, the sequence of actions becomes unconscious and automatic, freeing up attention to learn something else while flawlessly performing the action. At this point, implicit [procedural] memory is at work.

This process creates maximum efficiency for the horse and therefore training can only be successful when we create a positive long-lasting muscle memory for the horse. A handy rider can create the outlook of balance through mechanical training, but this way the effects will only last during the session. After dismounting, the horse goes back into its own (crooked) posture. However, if we work through muscle memory, the effects of training remain not only throughout the session, but also during the horse's 'free' time in the pasture/paddock.

While the process of creating muscle memory is advantageous on many levels, it needs to be done correctly as once it begins the behaviour sequence it can be hard to interrupt or change. This explains why constant repetition actually reverses progress and why a horse could remain in a bad posture for a long time when being trained or learned something improperly in the past.

Habits are also learned through repeated experiences and can become fixed and inflexible. Habit learning is a reflexive behaviour elicited by antecedent stimuli rather than controlled by sequences:

> *''Reaction time includes the time it takes to both initiate a response and complete a behaviour sequence. In many cases of sequence learning, the animal becomes slower to initiate the action but faster at completing the sequence, and this pattern is characteristic of habit learning.''* – Foster 2019

Thus, one can say that practise is good, but [endless] repetition is not. We have all heard that ''practise makes perfect'', but recent studies have shown that making variations on how we practise is much more effective than repeating the same thing over and over again. The same can be said for horses. Repeating a movement does not educate the horse's physique, but instead, *''equine education needs to create the body coordination appropriate for the effort.''* – Cornille 2017

Hence, an intelligent an tactful trainer leads the horse's brain toward a coordination of the equine physique precisely adapted to the performance. In many cases, this means the trainer has to 'rewire muscle memory' through intelligent questions and thus guide the horse's brain into efficient and advanced body control. Such education is based upon the partnership of two intelligences: *''the rider's intellect which has the capacity of analysis and the horse's mental processing which must incorporate the rider's insights.''* – Cornille 2017.

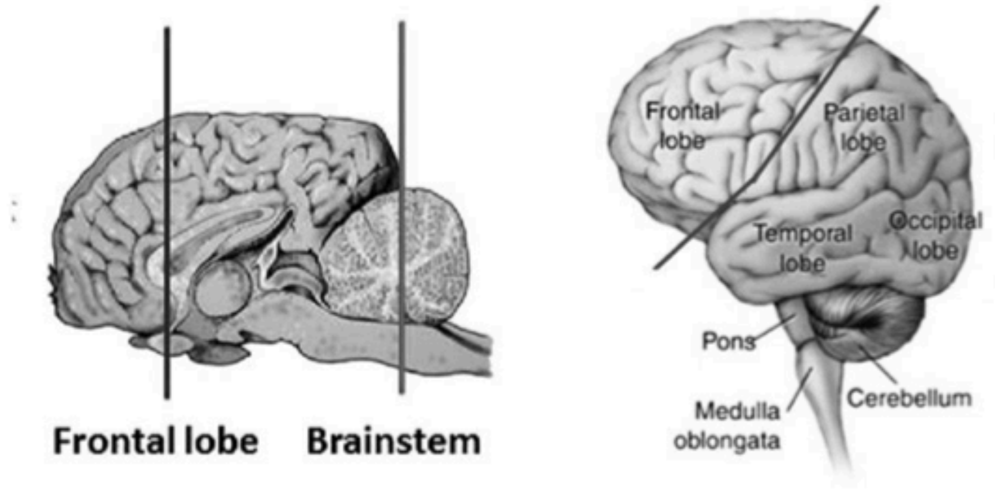
In the words of Nuno Oliveira: *''To practise Equestrian Art is to facilitate a dialogue on a higher level with the horse that requires courtesy and finesse.''*

This is the true application of equestrian tact as a primary and subtle aid to guide the horse's physical education and mental processing appropriately.

THE BRAIN

The brain of the horse is a highly complex organ. When discussing brain function, it's helpful to first consider the human brain since we can only think from a "human-centric" perspective which is the source of many frustration in handling horses.

Most conflicts simply arise because of the difference between the human brain and that of the horse. We've all been there: at the crossroads of the behaviour we want and the behaviour that the horse is giving you. Horses are very generous, but sometimes they're saying no to a certain question. The more we insist, the more they resist. The more we ask, the more they ignore.



(Left) Rech, R., & Barros, C., Neurologic Diseases in Horses, Veterinary Clinics of North America: Equine Practice, (31)2, 2015, 281-306; (Right) Nanda, U., et al. (2012). Image and Emotion: From Outcomes to Brain Behavior. HERD. (5) 40-59

Rough comparison of the difference in horse and human brains.

The biggest difference between the human brain and horse brain lies in the development of the cerebral cortex. In humans, 41% of the brain consists of the cerebral cortex – i.e. frontal lobe. This part of the brain is responsible for language, writing and all main executive functions such as planning, organizing and evaluating. This results that humans are ‘wired’ for goal-oriented behaviour which demands direct results from direct techniques. Thus, when a horse acts up, our human brain tries to insist and demand in order to achieve its goal.

In addition to the cerebral cortex, the human brain also facilitates a limbic system that is composed of structures in the brain that deal with emotions as well as memories. Activities related to food, sex, bonding and memories are all functions of the limbic system. The limbic system includes the Thalamus which collects incoming information such as sight, sound, smells, tastes, touches, verbal and non-verbal cues. The Basal Ganglia then prepare the body for movement in reaction to that information. At this time – unless we consciously hold it back - the cerebral cortex intervenes to consider the new data and determine whether and how to act – setting goals, creating strategies and planning steps to achieve those goals.

The equine brain on the other hand is mainly guided by the brain stem and cerebellum. This part of the brain – often referred to as the 'reptilian brain' - is concerned with survival and body maintenance. Digestion, reproduction, circulation, breathing, and the 'flight or fight' response are all reptilian brain functions. Because a horse is a motor/sensory animal, the horse is all but ruled by the cerebellum. The cerebellum plays a role in controlling balance, head, and eye movements. For the rest of the horse's life, the cerebellum will act as a library for storing all learning regarding physical movement.

Where the cerebral cortex is almost absent in the equine brain, the limbic system is quite well developed. In the horse, the Thalamus collections information. The Basal Ganglia then prepares the body for instant movement. There is no cerebral cortex that intervenes to hold reactions back and thus when the horse perceives something, it reacts instantly. Hence, we cannot expect a horse to learn in ways that require executive function because the equine brain simply does not have that capacity. This does not mean the horse is less intelligent, but simply that its brain is 'wired' differently.

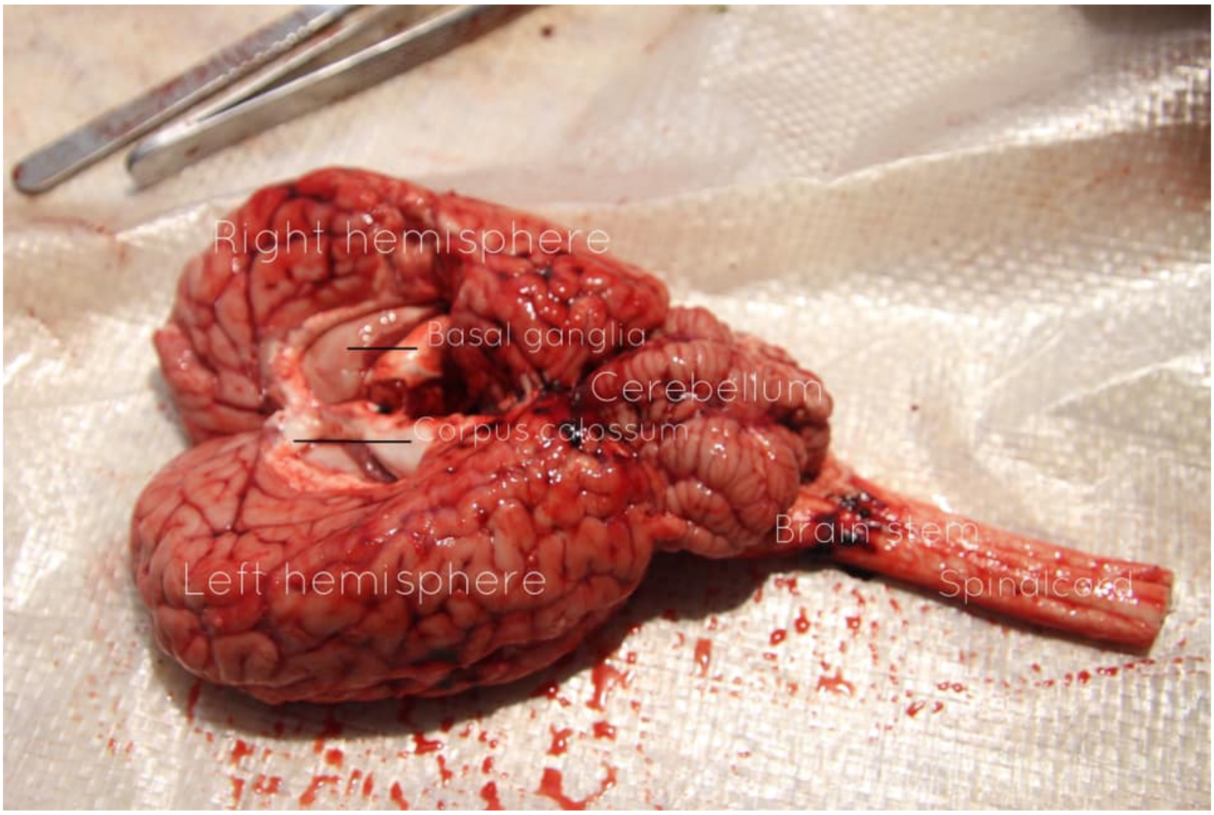
Hence, in order to train effectively, it is crucial to understand the consequences of the differences in the human and equine brain. The horse's brain focusses on one thing at a time, not on an order sequence of actions that lead to a long term goal. Specifically, the equine brain is designed to pay special attention to the emotion of fear:

> *''Just as our brains are designed for executive function, equine brains are engineered to pay special attention to fear.''* – Jones 2017

Fear is every teacher's enemy. Unfortunately, the human brain often pushes to direct means of training exactly when the horse's brain requires an indirect approach[3]. The mismatch between the approach favoured from a human brain perspective versus the approach desired from the equine brain perspective often is the main source for conflicts. A tactful trainer will understand the necessity of honouring the equine brain as there is no

[3] *The direct vs indirect approach will be discussed in the training modules*

use demanding that the horse thinks like we do.



A dissection picture of an equine brain

Thus, in summary it can be said that the equine brain can be somewhat classified into three progressive 'layers' with various functions that interact considerably, but differ from the human brain quite extensively:

- **The reptilian brain →** Consists of the brain stem and cerebellum. This part of the brain is concerned with survival and body maintenance. Digestion, reproduction, circulation, breathing, and the 'flight or fight' response are all reptilian brain functions. Because a horse is a motor/sensory animal, the horse is all but ruled by the cerebellum. The cerebellum plays a role in controlling balance, head, and eye movements. For the rest of the horse's life, the cerebellum will act as a library for storing all learning regarding physical movement.
- **The limbic system →** It includes the amygdala and hippocampus and interacts with the basal ganglia. This part of the brain is concerned with emotions,

motivation, pleasure and memory. Activities related to food, sex, bonding and memories are all functions of the limbic system.

- **Cerebral cortex →** Language speech and writing are functions within the cerebral cortex and makes up most of the human's brain. This large cerebral cortex versus the smaller version of the equine is one of the most notable differences between the way humans and horses operate.

PROPRIOCEPTION

The concept dates as far back as in 1557 by Julius Caesar Scaliger as a 'sense of locomotion'. Proprioception is often referred to as a sixth sense. Proprioception is from the Latin word *proprius*, meaning "one's own", "individual", and *capio, capere*, to take or grasp. Thus proprioception is the subconscious awareness of the relative position of the body and its limbs in space, their relationship to each other and the surrounding environment. It enables the maintenance of balance and control regardless of gait or type of work being performed and the need to consciously look at it or process the information.

Proprioception is facilitated by mechanically sensitive proprioceptor and sensory neurons distributed throughout the horse's body. A horse possesses three basic types of proprioceptors:

- **Muscle spindles →** these are embedded in skeletal muscle fibres
- **Golgi Tendon organs →** these lie at the interface of muscles and tendons
- **Joint receptors →** these are embedded in joint capsules.

The sensory systems of the horse include:

- **Visual perception →** The ability to interpret the surrounding environment using light in the visible spectrum reflected by the objects in the environment The resulting perception is also known as (eye)sight or vision.
- **Vestibular system →** provides the leading contribution to the sense of balance and spatial orientation for the purpose of coordinating movement

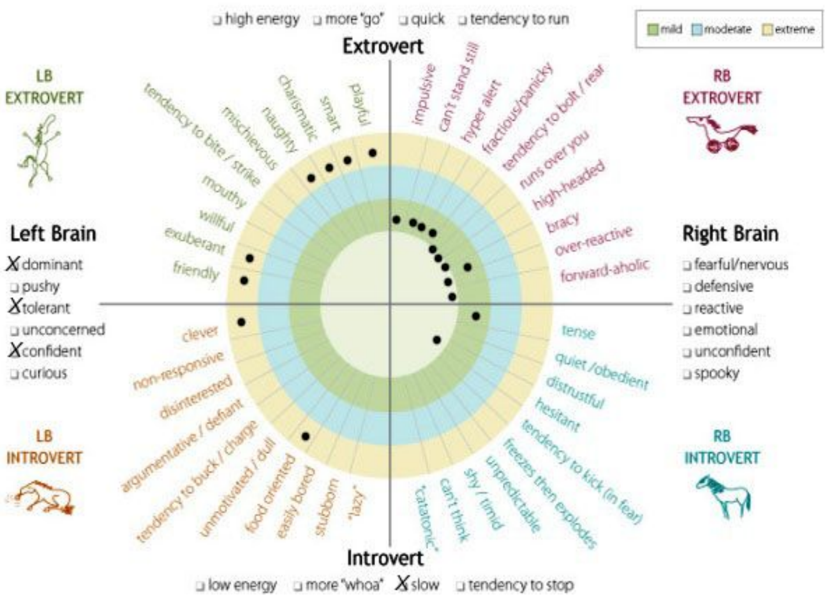
with balance. It consists of the *semi-circular canals* which indicate rotational movements and the *otoliths* which indicate linear accelerations.

The central nervous system integrates the information received from those proprioceptive and sensory neurons to create proper spatial awareness.

Proprioceptive deficit in the horse shows in the loss of spatial awareness of the body, limbs and/or head. It alters gaits and movement in a way that cannot be explained by changes in the limb. For example: ataxia, a change in the rate and force of movement, but also ECVM.

HORSENALITY

Just as with humans, horses have a personality – referred to as 'horsenality'. It is often believed that every human and horse have one side of their brain that is dominant and determines personality – or 'horsenality'. The left and right sides of the brain –the hemispheres- are connected by a great number of nerve fibres. In a healthy brain, the two sides communicate with each other. The left-right brain theory is based upon the lateralization of brain functions between the left and right hemispheres. The left part of the brain is usually considered to deal with logic and cognitive abilities whereas the right part of the brain is considered to deal more with emotion and creativity.



Picture adapted from Parelli showing their famous horsenality index of Left Brain/Right brain to Introvert/Extrovert scale.

The theory about left-right brain is not new. It is believed to have taken root as far back as the 1800s, when scientists discovered an injury to one side of the brain caused a loss of specific abilities. The concept gained ground in the 1960s based on the work of neuropsychologists Robert Sperry and Michael Gazzaniga. While studying the effects of epilepsy, Sperry discovered that cutting the corpus callosum – the band of neural fibres that connects the two hemispheres of the brain – could reduce or eliminate seizures. However, after the communication pathway between the two sides of the brain was cut, patients responded differently to stimuli, indicating that the hemispheres have different functions. For example, many split-brain patients found themselves unable to name objects that were processed by the right side of the brain but were able to name objects that were processed by the left-side of the brain. Based on this information, Sperry suggested that language was controlled by the left-side of the brain. Furthermore, other researchers discovered that the left-hemisphere seems to control muscles on the right side of the body while the right hemisphere controls those on the left. This is why damage to the left side of the brain, for example, might have an effect on the right side of the body.

The research related to specific functions of the two hemispheres of the brain, but some psychology enthusiasts were keen to take this work a step further by relating personality type to brain hemispheres leading to the myth that people and horses are either left- or right brained: *''It is absolutely true that some brain functions occur more in one or the other side of the brain (…) But people don't tend to have a strong left- or right-sided brain network'' (Anderson).*

In 2013, a comprehensive study looked at 3-D pictures of over 1000 human brains, measuring the activity of the left and right sides using an MRI scanner. Their results show that a person uses both halves of the brain and there does not seem to be a dominant side (Nielsen et al. 2013). The authors concluded that the notion of some people being more left-brained or right-brained is more a figure of speech than an anatomically accurate description.

So no matter how lateralized the brain can get, the two sides still remain to work together. The left-right brain theory can only be used a simplified concept – a figure of speech - to gain understanding of how to balance a horse mentally and emotionally. When only the sympathetic nervous system is activated, the horse will be emotionally unstable (stressed out/nervous/angry/anxious) and unable to learn new things, let alone coordinate bodily movements. It is then the task of the trainer to rebalance through the parasympathetic nervous system and bring the horse more into a 'thinking state of mind' so that the horse becomes mentally and emotionally stable. This can only be done when one masters its own emotions first.

NEUROSCIENCE AND INTELLIGENCE

Neuroscience and intelligence refers to the various neurological factors that are partly responsible for the variation of intelligence within a species or between different species. A large amount of research in this area has been focused on the neural basis of human intelligence.

The definition of intelligence is controversial. The word derives from the Latin nouns *intelligentia* or *intellectus,* which in turn stem from the verb *intelligere* meaning to comprehend or to perceive. Intelligence has been defined in many ways including: the capacity for logic, understanding, self-awareness, learning, emotional knowledge, reasoning, planning, creativity, critical thinking and problem solving. More generally, it can be described as the ability to perceive or infer information, and to retain it as knowledge to be applied towards adapted behaviours within an environment or context.

Human intelligence is thus the intellectual power of humans, which is marked by complex cognitive feats and high levels of motivation and self-awareness. It gives us the cognitive abilities to learn, form concepts, understand and reason, including the capacities to recognize patterns, comprehend ideas, plan, solve problems and use language to communicate. Intelligence enables us to experience and think.

DOES SIZE MATTER?

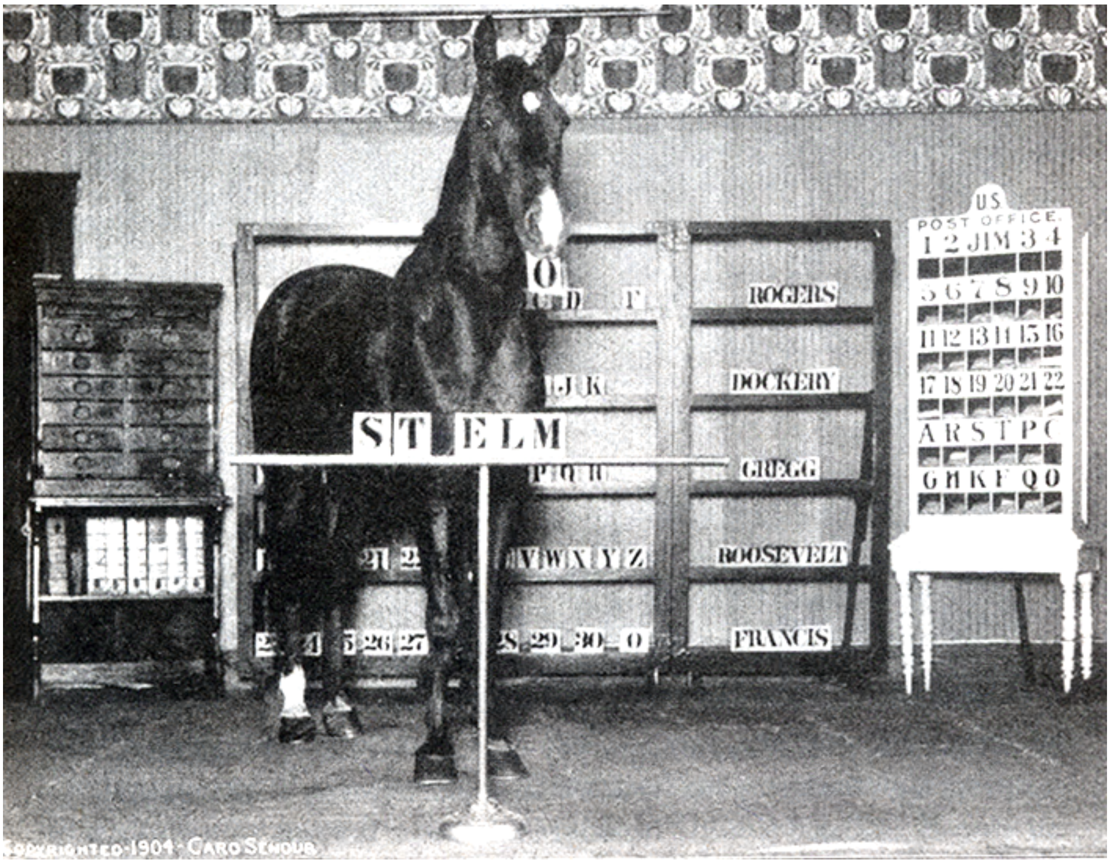
Brain size and weight is often equated with intelligence. The brain size usually increases with body size in animals, but relationship is not linear. A human's brain weights about 3 pounds; a horse's brain weights about 2.5 pounds. Furthermore, the horse's brain is proportionately about 1/650th of its body weight, whereas the human brain is about 1/50th of our body weight (Stephen Peters). Current research still supports that the brain ratio to body mass reflects a certain level of cognitive skills. However, it must be pointed out that some birds outclass the human brain ratio to body mass. For example, the brain of a shrew takes about 10% of its total body mass.

Yet, it is not quite clear what all this means in terms of the cellular constituents of brains. Several researchers argued that factors other than size are more highly correlated with intelligence, such as the number of cortical neurons and the speed of their connections (Roth and Dicke). Moreover, they point out that intelligence depends not just on the amount of brain tissue, but on the details of how it is structured. Neuroscientists always assumed that humans have more cortical neurons than any other species on the planet, no matter the size of their brain. However, a study (2014) of 10 long-finned pilot whales implied that these whales have roughly 37.2 billion neurons – about twice as much as humans do!

ARE WE SMART ENOUGH TO KNOW HOW SMART HORSES ARE?

For over centuries, others animals have been considered inferior to humans when it comes to intelligence – or more broadly cognition. Well-known French philosopher Descartes (17th century) believed animals were mindless and could neither reason nor feel pain. The work of Ivan Pavlov (19th century) and B.F. Skinner (20th century) portrayed animals in merely reacting *''reflexively to their environment, or behaving only in response to positive or negative reinforcement''.* Dr. N.H. Hodman, a veterinary behaviourist stated *''The extreme behaviourists' view that other animals' behaviour is to be observed and measured but not interpreted prevailed through much of the last century''.*

However, where scientists have been divided over the subject, most horse owners - and that other animals for that matter – would argue that of course horses are intelligent and have emotions. On a daily basis we observe that horses are capable of sophisticated behaviours, including sensory discrimination, learning, decision-making, planning and highly adaptive social behaviours. For example, already in 1904 a horse named Beautiful Jim Key became a world-wide sensation as the smartest horse in the world as he could perform basic arithmetic, read, write and spell.



Jim Key on stage spelling the name of celebrity Greyhound, St. Elmo. In the background are names of politicians, which Jim would retrieve at the request of audience members. Picture adapted from Beautiful Jim Key by Mim Eichler Rivas (2005).

So the question should not be whether horses are less or more intelligent, but whether we are capable to comprehend. Research starts to finally catch up to indicate that it may well be that the differences between humans and horses (and other mammals) are more quantitative than qualitive. In other words, the difference is probably more in degree than basic functioning, indicating that horses in fact have (some of the) cognitive abilities as we do, but maybe on a different level. So do horses understand us? Of course. Do they communicate with us? Yes. Do we know for sure what's going on in their minds? Nope.

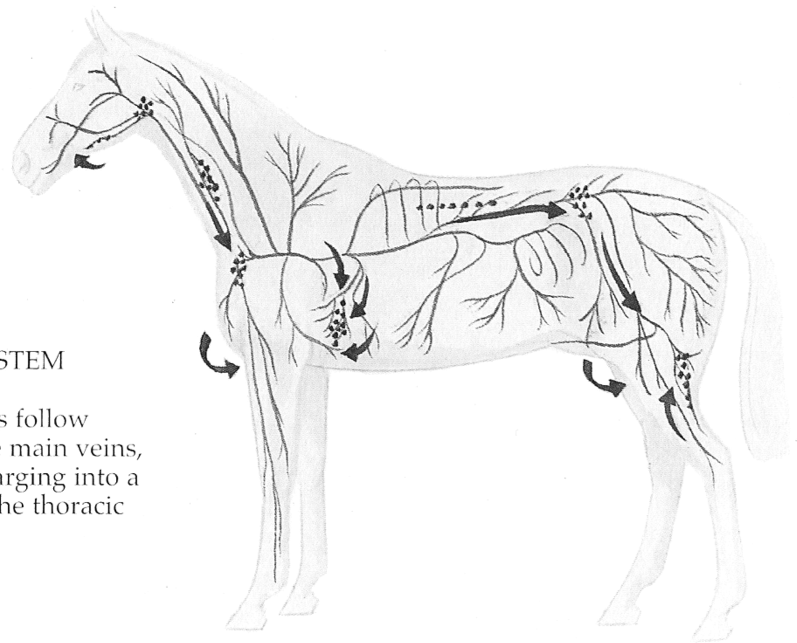
So it is not (relative) brain size or absolute number of neurons that distinguishes humans from horses. *''People forever ask for* the *single thing that distinguishes humans from all other animals, on the supposition that this one magical property would explain our evolutionary success—the reason we can build vast cities, ride horses, put people on the moon, write* Anna Karenina *and compose* Eroica'' *(Koch 2016)*. But the simple answer reveals our ignorance of how intelligent behaviour comes about – we don't know.

I personally believe there is a lot of magic in the not knowing as it allows us to just be in the moment and enjoy the company of our equine partners. To be amazed by them. To be humbled by them. There is a lot to learn from them. They're truly an unique species.

LYMPHATIC SYSTEM

Just as in humans, horses have two closely cooperating circulatory systems: the cardiovascular and the lymphatic system. Until recently, the lymphatic system has been rather neglected. This has led to it not only being overlooked, but also to the development of inaccurate information on its function within the body.

The lymphatic system is a low-pressure system, similar to the venous system. It is a system of ducts, collector vessels and nodes which drain excess lymph fluid from body tissues back into the blood stream and onwards to the kidneys.



LYMPHATIC SYSTEM

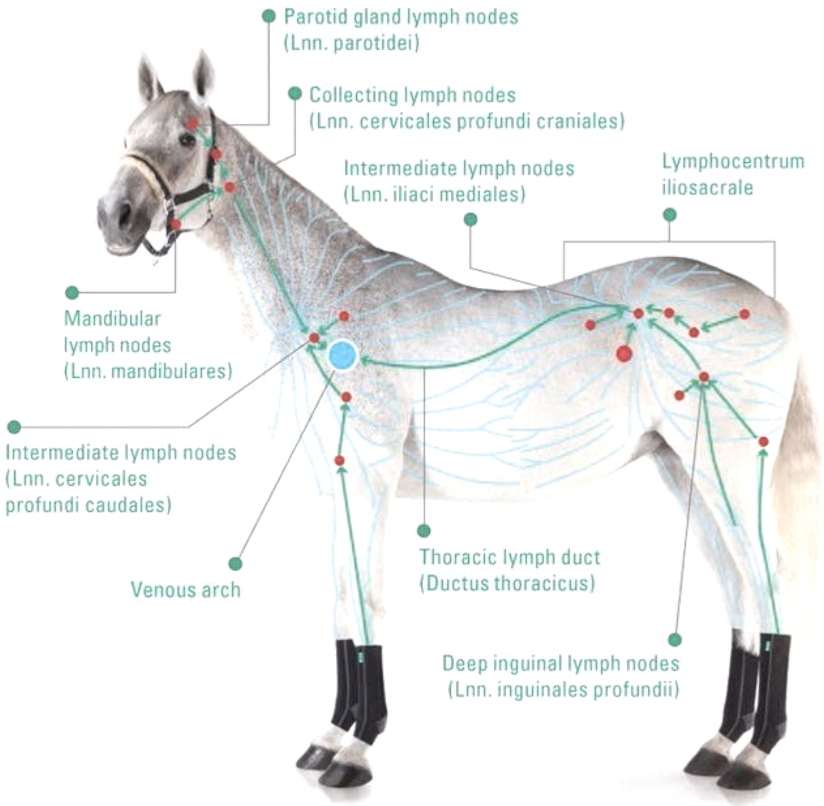
All lymph vessels follow the pattern of the main veins, eventually discharging into a venous vessel – the thoracic duct.

Unlike the venous system, the lymph system does not function as a closed circulatory system. The lymph vessels begin as open-ended capillaries in the intercellular space and ultimately flow into veins located near to the heart. The cardio-vascular and lymph systems work closely together and therefore are mutually dependent. Any disease in one system automatically affects the parallel system. Furthermore, it works closely together with the nervous system as well.

The lymphatic system not only includes the lymph vessels and lymph nodes, but also the spleen, thymus gland, pharyngeal lymphatic ring – tonsils and lymphoreticular tissue – as well as the lymphatic tissue of the intestines.

Lymph forms an intercellular fluid and thus its composition largely corresponds to that of blood plasma – with difference in the amount and type of blood cells. But lymph nodes also encapsulate harmful components of the lymph fluid. Lymph mainly consists of water, plasma proteins, hormones, enzymes, cellular debris and foreign substances (i.e. bacteria and viruses during infections).

Lymph drains towards the heart. The main lymph vessel is the thoracic duct, which collects the lymph from the afferent lymph channels of the hind limbs, abdominal cavity and the unpaired abdominal organs – intestine, stomach, liver and spleen – and feeds it into the venous blood.

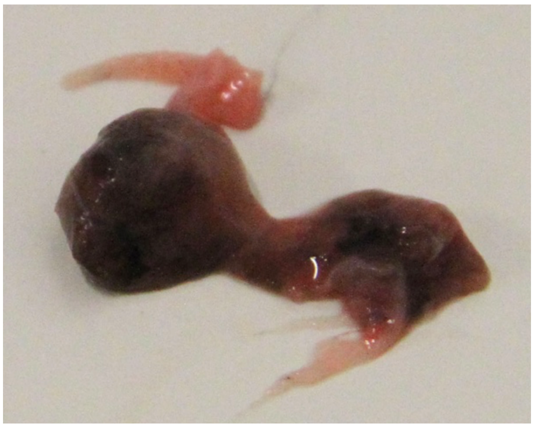


The lymph nodes are embedded in the drainage system and serve as filter points for the lymph. The horse has about 8000 lymph nodes irregularly distributed throughout its body. However, the lymph nodes are quite densely concentrated in the lymph node centres. In case of infections, these become noticeably swollen. Depending on their position, the lymph node centres are not always visible and palpable, but the mandibular ones are very easy to palpate.

The lymphatic system is a very active, sensitive and highly complex structures with several important functions:

- **Immune surveillance →** fighting of pathogens
- **Drainage and transportation of waste -->** proteins, fluids, fats and cells back into the bloodstream.

The lymphatic system ensures the removal of tissue fluid. This tissue fluid originally comes from the bloodstream and supplies the cells with nutrients. Cells, in turn, release waste into this tissue fluid. A properly functioning lymph system ensures that tissue fluid and waste do not remain behind in the tissue but are quickly removed. The function of the lymphatic system is to clean the body from, among other things, germs, and waste products. Because the lymph system also removes germs, it has a clear effect on the immune system. Furthermore, lymph contains of white blood cells - called lymphocytes – that help fight infection and form antibodies.

Left: healthy lymph nodes in tissue. Right: unhealthy lymph node. A blackened lymph node could be inflammation or melanoma.

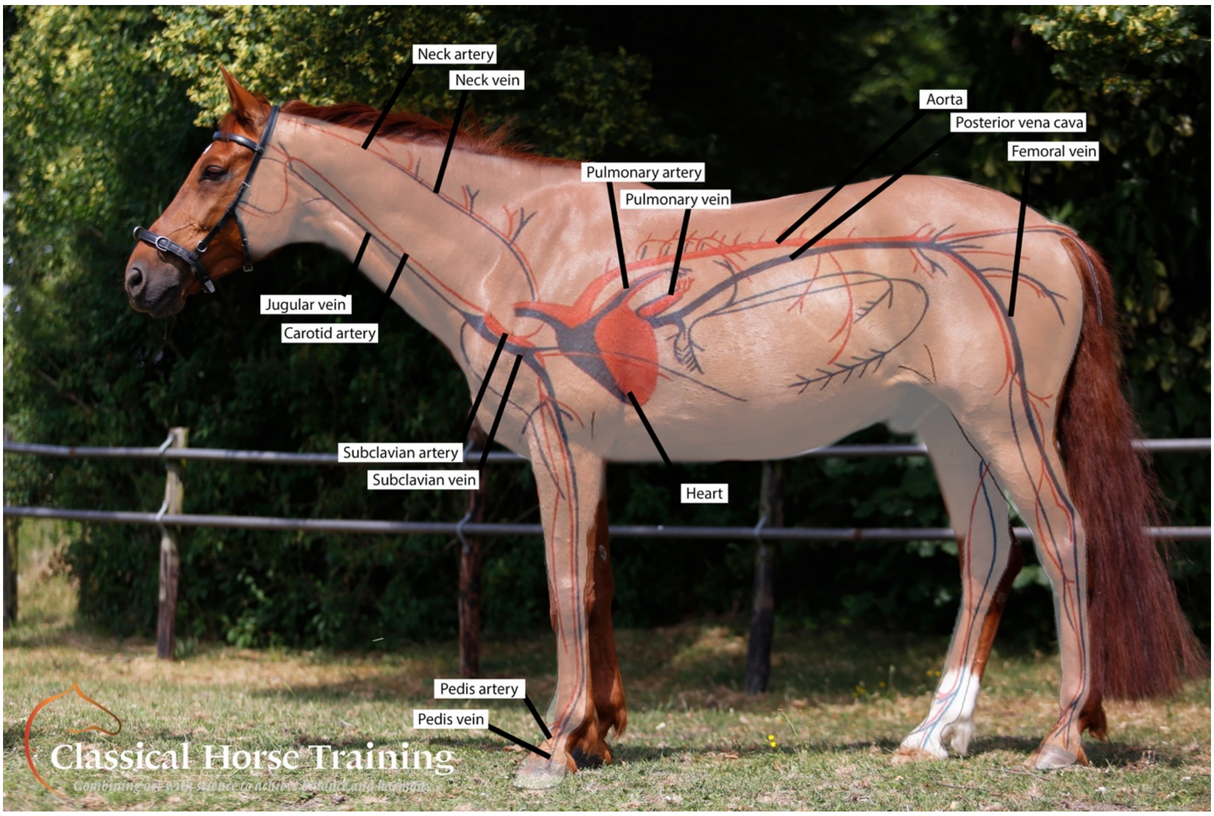
When the lymph system in an area is at maximum carrying capacity it leads to leakage of lymph fluid, which is called OEDEMA – for example a thickened leg.

CARDIOVASCULAR SYSTEM

The horse's innate athletic ability is largely due to a specialized circulatory system that, along with the respiratory system, can accommodate the large oxygen demands of the muscles in an exercising horse[4].

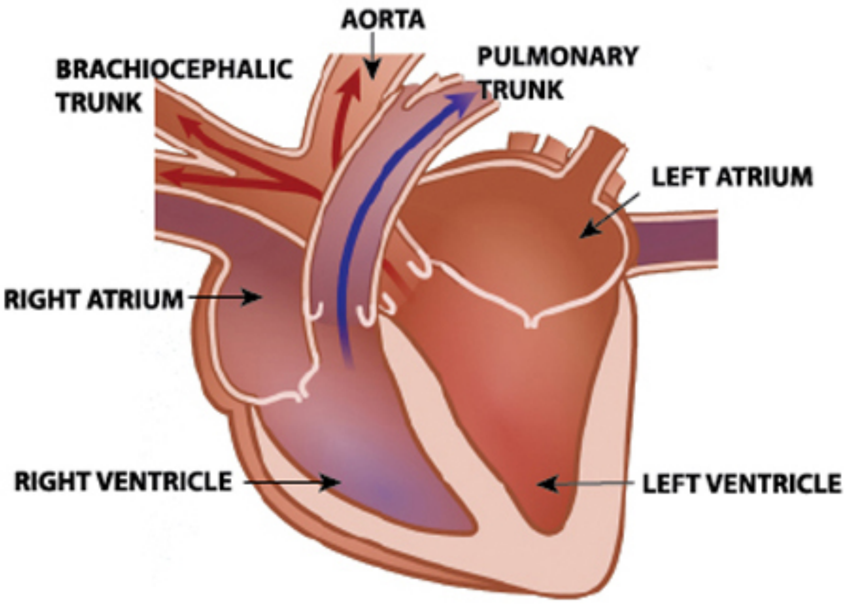
This circulatory system transports blood throughout the horse's body via a network of vessels. The number of litres of blood represents about 10% of the horse's total body weight.

The equine circulatory system consists of two major organs, the heart and spleen, which are connected by a vast array of vessels that serve to deliver oxygen and nutrients to the cells of the body and remove wastes and toxins those cells produce.



[4] *See manual on physiology for more info on the relation between the cardiovascular system and the superior athletic capacity of the horse.*

As in humans, the equine heart is central to the circulatory system. Put simply, the heart can be described as a large muscular pump made up of cardiac muscle fibres (see chapter about muscles). The heart can weigh up to 5.5kg in a large horse and increase in size as the horse becomes fitter, for example the great racehorses Phar Lap (6.35kg). Its primary function is to send blood via a network of vessels throughout the body in order to supply bodily tissues with nutrients, such as O2 and absorbed carbohydrates.



THE EQUINE HEART

The heart is split up into four chambers:

- **Left and right atrium**
- **Left and right ventricle**

The chambers on the right control the venous – deoxygenated – blood and transports it to the lungs for oxygenation. The left sided chambers on the other hand control the arterial – oxygenated – blood from the lungs and sends this to the body.

This vitally active system between the heart and lungs is known as the pulmonary system. The venous blood flow is conducted through veins whereas the heart pumps the oxygenated blood through arteries. This is a common functional rule except in the case of the pulmonary system, whereby the pulmonary artery leaves the right ventricle with deoxygenated blood and returns to the heart via the pulmonary vein with oxygenated blood (May-Davis 2017).

The heart rate of a horse provides information of how body and mind are coping with a certain set of circumstances at a given point in time. There are two main methods to measure heart rate:

- **Listening via a stethoscope →** above the point of elbow on the left side
- **Slightly pressing an artery close to the surface →** pulse can be felt with a forefinger

The heart rate should be measured for a least one minute to ensure accuracy. If that is not possible, then a multiplier can be used to determine the beats per minute.

Heart rate is affected by:

- **Gender →** in general, mares have slightly faster rate than stallions or geldings
- **Excitement →** increases heart rate
- **General condition →** conditioned horses generally have a slower rate at rest than normal horses (this is a questionable statement as it is deemed that a heart rate is genetically influenced. However, experience is proving to be somewhat different.
- **Exercise →** increases heart rate according to intensity. It can reach 260 bpm at the gallop
- **Digestion →** good digestion decreases heart rate whereas issues in the digestive system increases heart rate.
- **Weather →** cold weather decreases heart rate, warm weather increases heart rate

- **Fever and pain →** Increases heart rate
- **Age →** higher in the first five years of the horse. From there, adult horses have an average of 28-40 beats per minutes.

RESPIRATORY SYSTEM

The respiratory systems encompasses the upper and lower airways. The nose, sinus cavities and pharynx constitute the upper airways, whereas the lower airways comprise the larynx, trachea, alveoli, pleurae and the lungs. The respiratory system has multiple functions:

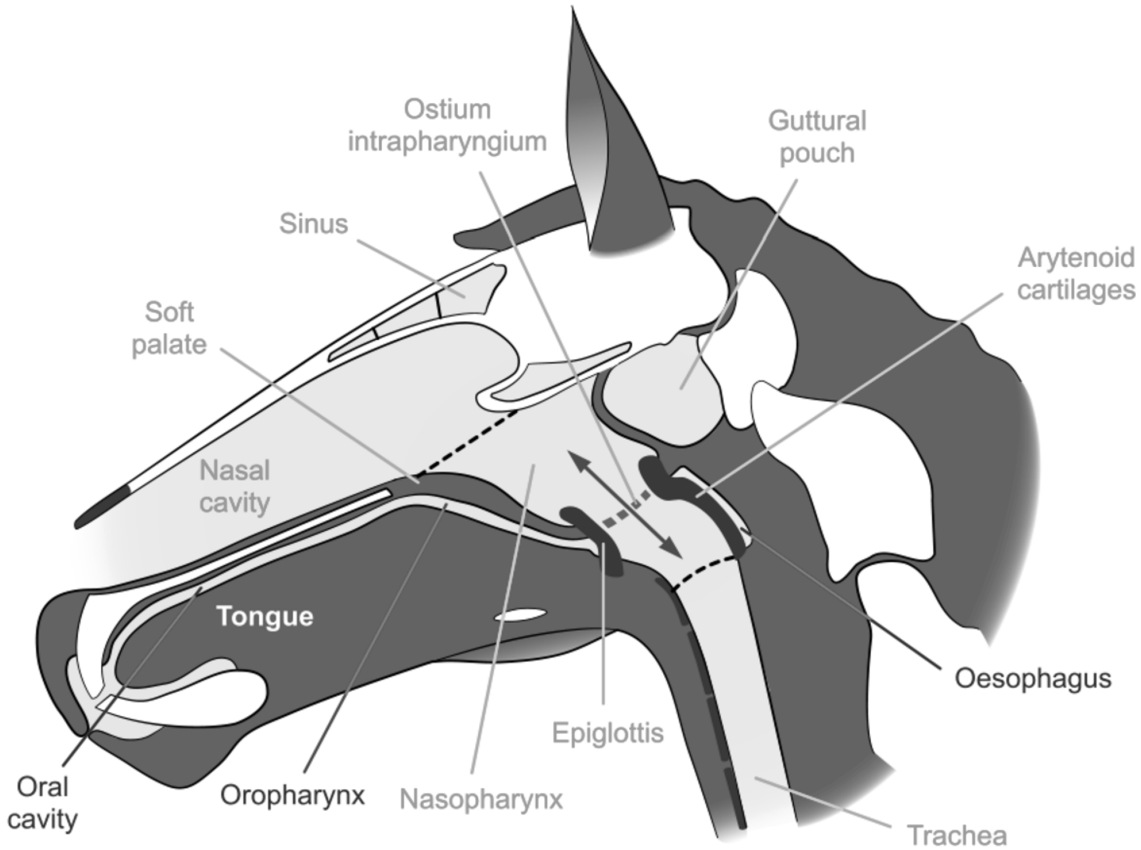
- **Gas exchange →** CO2 and O2
- **pH control →** regulation in acidity
- **Temperature control**
- **Water elimination**
- **Production of voice →** e.g. neighing
- **Production of sense of smell →** e.g. nasal cavity

As a flight animal, it requires considerable amount of oxygen to enable the horse to keep enough kinetic energy available in its muscles. Furthermore, the horse is often asked to engage in athletic performances. The harder a horse works, the more oxygen it needs and the more air it must move into and out of the lungs. By the time a horse finishes a race or completed a grand prix jumping course it will have moved somewhere around 1800 litres of air in and out of the lungs. Think about it, this is about 6 bathtubs full of air. Therefore, the lungs of the horse are relatively large and occupy most space behind the ribs and are separated from the abdominal wall by the diaphragm – a the only impaired membranous muscle in the horse's body. When fully expanded, the lungs can reach to the 16th rib of the horse.

The respiratory system provides an open passageway for air to get sucked into the lungs. The longs are expanded with help of the diaphragm which contracts away from the thoracic cavity, thereby decreasing the pressure and pulling air into the lungs. Once in the lungs, the oxygen diffuses into the blood so the lungs get fully oxygenated. At the same time, carbon dioxide is released by the blood, exchanged for oxygen and then exhaled again.

Respiration involves:

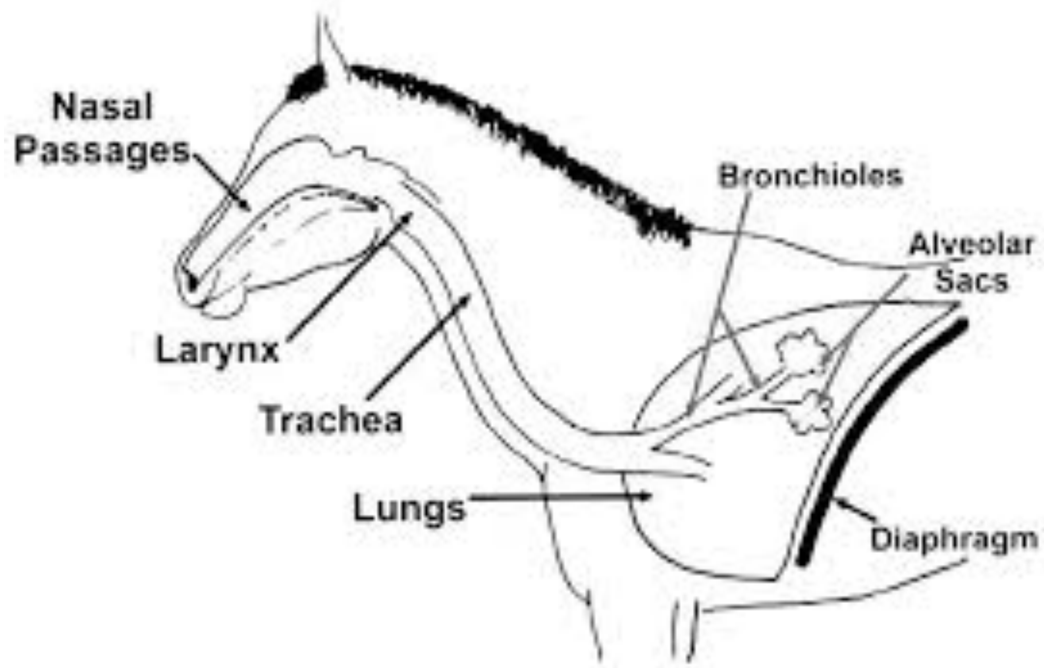
- **Inspiration (breathing in)** → Inflow of air into the lungs. Contraction of the diaphragm forces the abdominal contents caudal and aids the increase in size of the thoracic cavity along with the intercostal muscles. This results in the lungs following the expansion of the diaphragm and thorax, resulting in the inflow of air into the lungs.
- **Respiration (breathing out)** →Flow of air out of the lungs. This happens whenever the volume of the thorax is decreased. This process is largely passive because of the tendency of elastic structures of the costal cartilages, lunges and abdominal wall to return to their normal shape and location – without muscular effort.



The respiratory tract starts at the nostrils and nasal passages. This is also the place where the horse's olfactory receptors – those responsible for the sense of smell – are located. Due to the large length of the nasal cavity there is a large area of receptors and therefore the horse has a better ability to smell compared to a human. Additionally, the horse also has a vomeronasal organ – or Jacobson's Organ – which is in the hard palate and able to pick up pheromones and other scents when a horse shows the what is known as the 'flehmen response'. The flehmen response forces air through slits in the nasal cavity and into the Jacobson's organ.

When air is inspired through the nostrils, the air is warmed and humidified, and large particles are trapped so they cannot continue down the respiratory tract. The air then travels to pharynx which delivers air from the nasal passages to the larynx as well as delivers food from oral cavity to the oesophagus (see digestive system). Interestingly, horses are different to humans in the sense that they can't breathe through the mouth as the oral cavity and pharynx are always separated by the soft palate except for swallowing. The horse is thus the epitome of the proverb "The nose is for breathing, the mouth is for eating''.

So the pharynx brings the air to the larynx which prevents food from getting inhaled into the lower airway. From there, the air is passed into the trachea which delivers the air to the bronchi. The bronchi branch into bronchioles which then finally branch to the alveoli where the oxygen exchange occurs. Oxygen diffuses from the alveoli of the lung into the pulmonary capillary circulation where it is picked up by haemoglobin and transported by the bloodstream to the muscles. The muscles use oxygen to burn fuels from the horse's diet (carbohydrates and fats) to produce the energy necessary for muscle contraction. Carbon dioxide is the by-product that is exhaled. When inhaled, the air contains about 20% of oxygen. When exhaled, it contains about 16% of oxygen. About 4% of oxygen that streams into the lungs is replaced by the same quantity of carbon dioxide.



There are two forms of respiration:

- **Internal respiration →** Occurs in metabolizing tissues, where oxygen diffuses out of the blood and carbon dioxide diffuses out of the cells.
- **External respiration →** Exchange that occurs in the lungs where oxygen diffuses in the blood and carbon dioxide diffuses into the alveolar air

Classifications of breathing:

- **Eupnoea →** normal quiet breathing
- **Dyspnoea →** difficult breathing
- **Apnoea →** Absence of breathing
- **Hyperpnoea →** increased depth and/or rate of breathing
- **Polypnea →** Rapid, shallow breathing

Types of breathing:

- **Diaphragmatic breathing →** This occurs during ordinary quiet breathing - eupnoea.
  It requires minimal abdominal movement due to the diaphragm contracting and forcing the abdominal contents caudally.
- **Costal/ Thoracic breathing →** This occurs if more air is needed than the normal diaphragmatic breathing is provided.

A normal respiration rate of a mature horse at rest lies between 8-16 breaths per minute. New-born foals have respiration rates between 60-80 breaths per minute whereas older foals usually have between 20-40 breath per minute. You can measure respiration by watching the horse's ribcage going in and out – an inhale and exhale is one breath – or feeling the air coming out of the nostrils. Remember, if your horse or foal becomes excited for whatever reason, the respiratory rate can become temporarily elevated. Heat and humidity can raise the respiration rate considerably, especially if the horse has a dark coat and is in the sun.

Regular breathing is a reflex action, but can also be consciously controlled by the brain. The respiratory centre of the brain contains the following structures:

- **Medulla oblongata** → Made up of the **dorsal and ventral respiratory neuron groups.** The dorsal group initiates inspirations whereas the ventral groups controls the exhalation area. Together, they control the basic rhythm of respiration.
- **The pons** → Made up of the pontine respiratory neurons group which includes two areas knows as the **pneumotaxic centre** – associated with deep inspiration e.g. sighing – and the **apneustic centre** which prevents over distension of the lungs and inspiration occurring before expiration is finished.

The way this works is pretty straightforward. When the horse is asked to engage in athletic performance, its body demands to take in more oxygen to be delivered to the muscles. Both the respiratory and circulatory system need to make sure that the oxygen is getting to the muscles faster than when resting. Furthermore, they need to make sure that the CO2 produced is removed efficiently. The medulla oblongata basically detects carbon dioxide (CO2) and oxygen (O2) levels in the bloodstream and determines what changes need to happen in the body. It can then send nerve impulses to muscle in the heart and the diaphragm letting them know that they need to step up their game. The horse's respiration rate increases. The amount of air moved in and out of the lungs increases in direct proportion to how fast the horse is running. If a horse runs twice as fast, it must move twice as much air in and out. The horse's heart also starts beating faster as not only does the oxygen need to get into the body, but it needs to be delivered to the muscles as well.

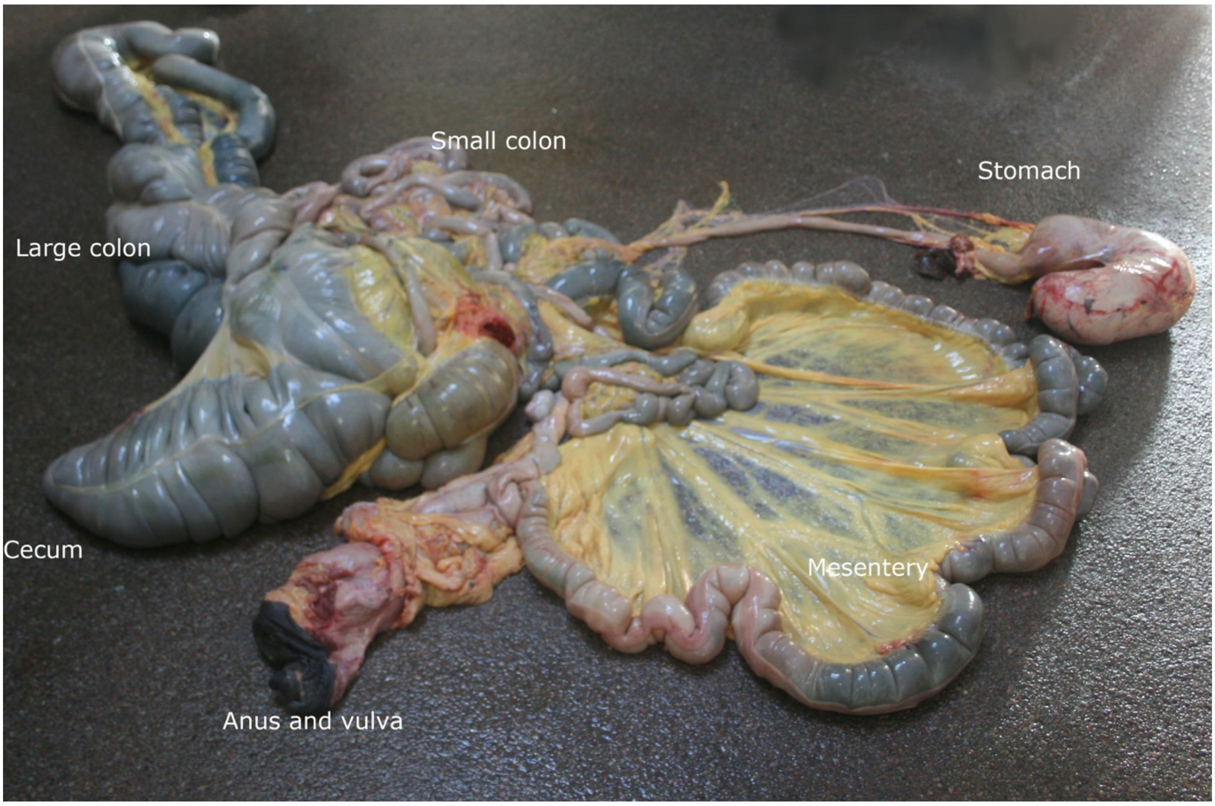
When horses inhale during exercise, around 90% of the resistance to air movement is in the airways that are in the head, namely, the nostrils, the nasal passages, and the larynx. But when horses are exhaling the majority of resistance to air movement (55%) is in the airways within the lung.

The "locomotive-respiratory coupling system" is a term used when the respiratory rate is linked to the horse's gait. This synchronisation of stride to breathing occurs primarily at the gallop. As the head is raised during the stride, the gut moves back and the horse breathes in. As the head is lowered during the stride, the gut moves forward and the horse breathes out.

From a riders perspective it is important to realize that we sit on the lungs. When fully expanded, the lungs can reach to the 16th rib of the horse. Therefore, any ‘kicking of the legs’ or ‘squeezing’ of the thighs affects your horses breathing process in a negative way and should always be avoided. If you tighten a horse’s girth too much, it will affect the horse’s performance–not because of constricting the chest and preventing the lungs from expanding, but because it decreases the effectiveness of the muscles around the front of the chest and shoulder that move the front limbs.

Finally, there is quite some discussion whether you can train the respiratory system of the horse. Plenty of books will tell you that you can. However, a number of scientific studies show the reverse demonstrating that the amount of air moved in and out by an unfit horse at a fixed speed will be the same six months later when that horse is fully fit (Marlin 2007).

DIGESTIVE SYSTEM

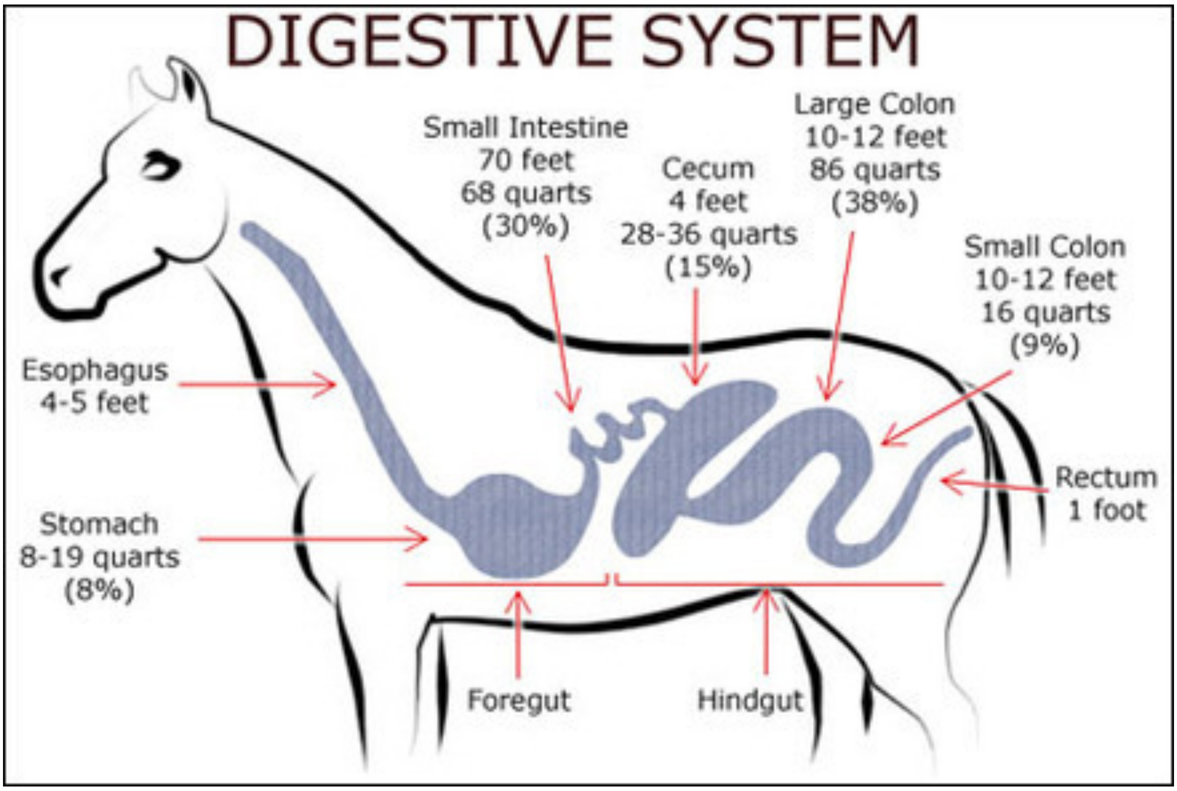


The horse is a non-ruminant herbivore. Non-ruminant means that horses do not have multi-compartmented stomachs as cattle do. Instead, the horse has a simple stomach that works much like a human's. Herbivore means that horses live on a diet of plant material. The equine digestive tract is unique in that it digests portions of its feeds enzymatically first in the foregut and ferments in the hindgut.

The gastrointestinal tract is a muscular-membranous tube that extends from the mouth to the anus. In a 16hh horse, it can approximate up to 30m in length.

The digestive system can be divided into two parts:

- **The foregut →** consists of the mouth, pharynx, oesophagus, stomach and small intestine.
- **The hindgut →** consists of the large intestine, rectum and anus.



Furthermore, the liver, pancreas and salivary glands are accessary digestive organs and provide enzymatic secretions necessary for digestions. It is important to note that, unlike humans, a horse has no gall bladder and hence, no gall stones.

Since the functions carried out in the front- and hind gut are very different it makes sense to focus on each part separately.

FOREGUT

The processes of the foregut start by the ingestion of food through the horse's mouth. The tongue moves the food to the molars where it is grinded through a series of chewing movements. The salivary glands – which can produce up to 12 litres of saliva a day – aid to moisten the food and form it into a ''ball like mixture'' which is called a (food) bolus. Furthermore, saliva contains an alkaline – bicarbonate – that helps to neutralize stomach acids and an enzyme – amylase – which aids in the process of digestions.

Once the chewed and moistened food has been formed into a bolus, the pharynx will guide it into the oesophagus by the process of swallowing:

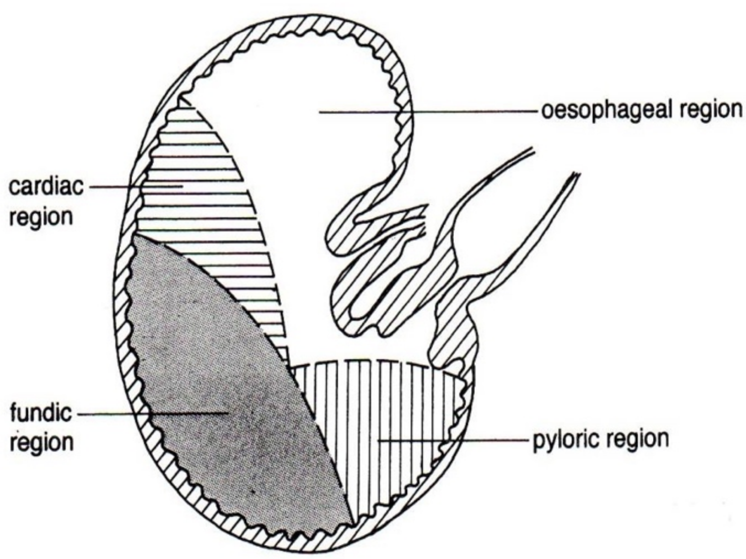
> *''The tongue pushes the bolus into the pharynx, which elevates the soft palate, closes the epiglottis over the larynx and guides the bolus into the oesophagus. This mechanism prevents foodstuffs entering the trachea.''*
> - May-Davis 2017

Once the bolus of food has been swallowed, the oesophagus moves it into the stomach along the digestive tract by waves of muscular contractions known as 'peristalsis'. The oesophagus is a muscular tube of roughly 1.2-1.5 meters long. If the food bolus gets obstructed here, the horse will choke resulting in the well-known phenomenon oesophagus congestion. The passage of food from the oesophagus to the stomach is controlled by a muscular valve called the 'cardiac sphincter'. This valve is very powerful and only functions one-way explaining why horses can't vomit. Therefore, in cases of severe stomach issues, it often ruptures before a horse could vomit.

So after the food has been chewed and swallowed the stomach kicks into gear. The main functions of the stomach are to store the incoming food boluses, add gastric acid to help with the breakdown of the boluses, to secrete the enzyme pepsinogen to begin protein digestion, and to regulate the passage of food into the small intestine. Basically the stomach is a holding and mixing tank, not unlike a cement truck that is constantly churning and mixing ingredients. Lying under the diaphragm, the stomach is divided into four regions:

- **Oesophageal region →** Otherwise referred to as *saccus ceacus.* This region is responsible for storage of the food boluses
- **Cardiac region →** This area contains mucous secreting glands - called cardiac glands -
- **Fundic region →** This area contains enzymes, mucus and hydrochloric acid
- **Pyloric region →** This area contains enzymes and mucus.

Picture adapted from Pilliner and Davies (1996).



Mucus is used as a lubricant for materials that must pass over membranes, e.g., food passing down the oesophagus. Mucus is extremely important in the intestinal tract. It forms an essential layer in the colon and in the small intestine that helps reduce intestinal inflammation by decreasing bacterial interaction with intestinal epithelial cells. A layer of mucus along the inner walls of the stomach is vital to protect the cell linings of that organ from the highly acidic environment within it. Mucus is also secreted from glands within the rectum due to stimulation of the mucous membrane within.

The stomach holds between 8-10% of the total gut volume. Due to its shape and size, food remains in layers in the stomach for approximately 45 minutes and the pyloric sphincter controls the passage of food exiting the stomach into the small intestine.

True digestion only begins in the small intestine that received the liquefied feed material from the stomach. With assistance from enzymes secreted by pancreas into the small intestine, it is the main site for digestion and the absorption of protein, carbohydrates - sugar and starch - and fat. The small intestine is a tube like structure that is approximately between 20-27 metres in length. It holds between 55-70 litres and can be divided into three parts:

- **Duodenum** → Roughly 1 meter in length. This is the area where pancreatic and liver secretions are delivered.
- **Jejunum** → Roughly 20 meter in length and thus makes up for the main region of the intestine. This is the area where the majority of absorption occurs. It is important to note that this structure lies to the left in the abdomen.
- **Ileum** → Roughly 1-1.5 meters in length and together with the jejunum is also part of the area where most absorption occurs. It is important to note that this structure lies to the left in the abdomen.

The small intestine is also the main site of nutrient absorption once they are in small enough form. Amino acids, glucose, fat soluble vitamins (such as A,D, E and K), minerals (such as calcium and phosphorus), and fatty acids are taken into the body as they move along the small intestine, so progress shouldn't be too fast or too slow[5].

HINDGUT

The next segment in the digestion process, the hindgut, start with the large intestine and end in the anus.

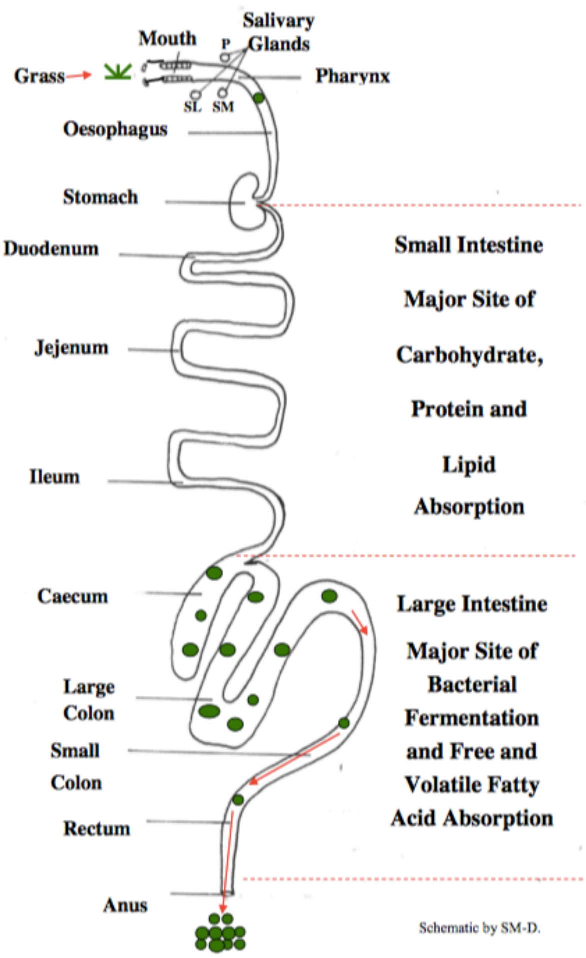
The processes that occur in the hind gut are less about breaking down food into smaller, absorbable particles with the aid of enzymes and more about fermenting complex carbohydrates into useful end products with the assistance of the "good bugs" (Gray 2016).

[5] *See manual on Basic Physiology for more information*

The large intestine is about 8 meters in length and the ingested food remains here for 36-38 hours. It houses bacteria and ferments the fibrous material in the food that the horse is unable to break down by its own enzymes. In addition to generating fatty acids, which supply energy or calories, the helpful ''good bugs'' also produce vitamin B and K, and some amino acids. The colon then not only absorbs these nutrients but also a large amount of the water that accompanies food as it moves along the digestive tract. This function occurs very efficiently such that by the final step in the small colon, the waste material not used by the horse is formed into faecal balls. These are subsequently passed into the rectum for evacuation through the anus.

The large intestine can be divided into three parts:

- **Caecum →** a large 'sac' holding between 25 – 35 litres of ingesta which can reach her in three hours after the food has been chewed. The entrance of the caecum – the *ileo caecal* valve – lies close to the right coupling with caecum lying in a forward -downward position before ending on the bottom of the abdominal floor.
- **Large colon →** Holds about 90-110 litres of ingesta and is about 3-4 meters in length. It 'folds' into four regions throughout the abdomen with turning points – flexures – that are most likely points of blockage.
- **Small colon →** Holds about 9-70 litres and is about 3-4 meters in length as well. It lies intermingled with the jejunum and moves quite fairly. However, it can cause a crisis through what is called a 'twisted gut'.



The small colon is followed by the final segments of rectum and anus. The rectum is about 30 centimetres in length, connecting the small colon to the anus, and functions as a storage for faeces that finally gets eliminated out of the body through the anus. The anus has a sphincter muscle dividing the digestive tract from the outside environment.

The cycle of mastication and digestion is now complete. In summary, please see the diagram below that illustrates a schematic view of the full processes of the digestive system.

INNER ORGANS

It is easy not to think too much about your horse's inner organs. As long as there's some indication that they're working – such as normal neurological responses, good appetite, good faeces and proper urinating – you probably don't invest a lot of time wondering just how well they function. It is easy no not take notice and hence, once we start seeing problems, the organ might already be failing. Therefore, it is worth to spend some time to getting to know your horse's inner organs a bit better.

SPLEEN

The spleen is a lymphatic organ located between the kidney and the small colon on the left side of the abdomen, lying against the ribcage. A so-called nephrosplenic ligament connects the spleen to the left kidney. It has two main functions:

- **Storage of red blood cells**
- **Production of lymphocytes**

There are two types of spleen. The defensive type, found in humans, primary functions to filtrate blood, remove foreign materials and bacteria and produce lymphocytes. The storage type of spleen is larger and, in addition to these defensive functions, serves as a reservoir for red blood cells. The spleen of horses, dogs and cats is classified as the storage type and therefore differs from human spleens mostly due to this storage function. However, the horse is thus not unique in this regards because the spleen of the dog and cat serve a similar storage function.

The storage ability of the equine spleen plays an important role in the horse's athletic ability. When the horse comes in to action – for example during exercise – the spleen contracts and release the stored red blood cells into general circulation. The spleen has the capacity to pump twelve extra litres of bloods within seconds, supplying the body with enough oxygen to enable the horse to perform quickly and enduring.

Apart from its major contribution to athletic performance, the spleen also plays an important role within the immune system through the production of lymphocytes which is a type of white blood cell that filtrates the blood by removing all useless or dangerous elements – including bacteria – and old blood cells. Blood cells, especially the red ones, have a fairly short lifespan and it is the job of the spleen to recognize and remove old and degenerating cells from the circulation. In addition, important substances in the blood are stored as well as possible.

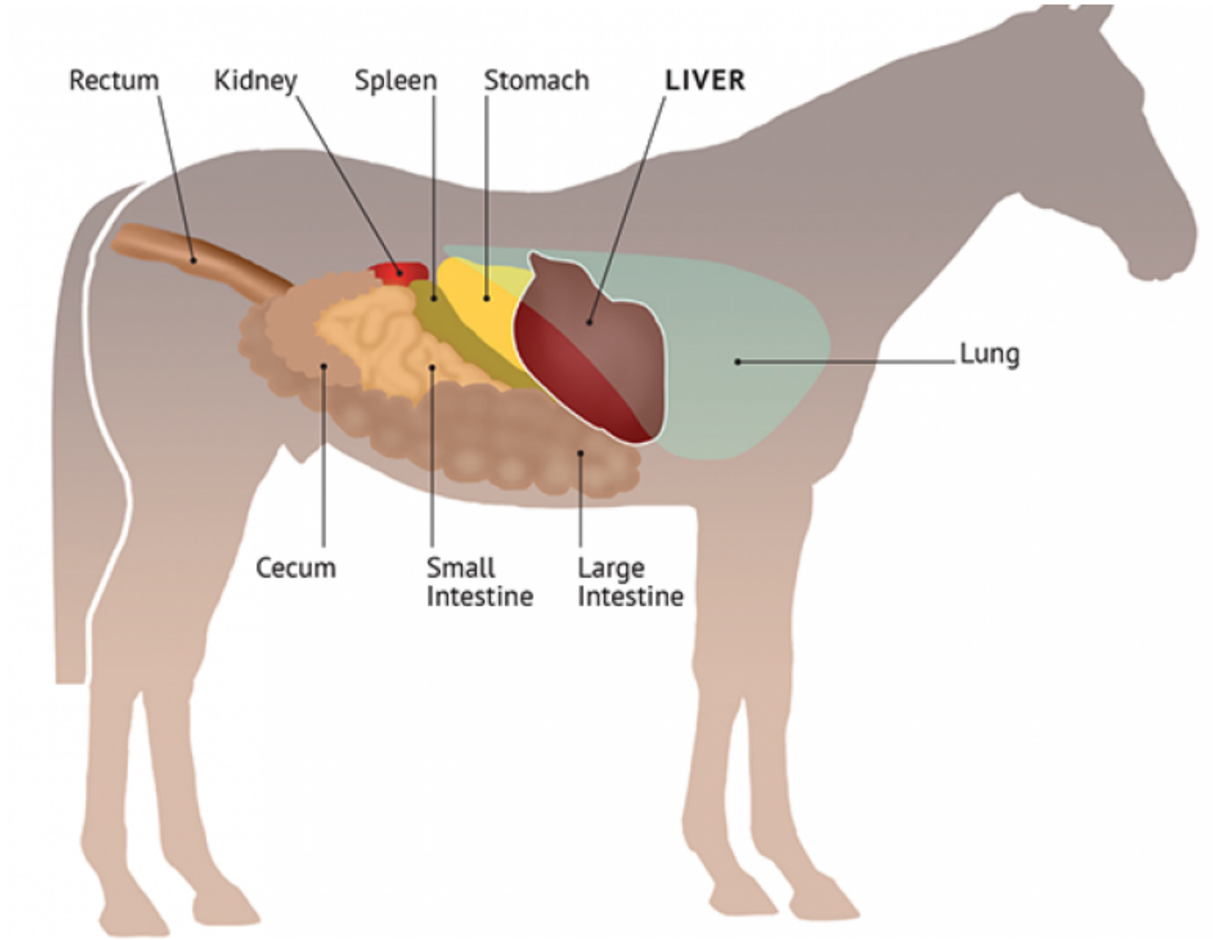
Although its important functions, it is not essential to life. However, knowing the important role it plays during exercise, horses whose spleen has been removed suffer a sharp decline in athletic ability (Geor 2001).

A spleen with scar tissue

LIVER

The liver is an organ that is usually described as part of the digestive system, but its functions extend far beyond that. It is estimated that the equine liver performs about 500 distinct functions (Kellon 2015). The liver is the largest internal organ and can be classified as both an organ and a gland. It is also the only tissue that has any significant ability to regenerate itself.

On the digestive end, the liver produces bile. Bile is an alkaline fluid which is essential for the processing and absorption of fats and fat soluble vitamins as well as altering the pH value of food that enters the gastrointestinal tract. In most mammals, bile is secreted from the liver and stored in the gall bladder, only to be released when needed. However, a horse doesn't have a gall bladder. Therefore, bile cannot be stored and must be deposited directly into the intestine in response to feeding. This is one of the reasons why horses must be slowly adapted to high-fat diets, as bile volume and composition must be altered over time to allow proper digestion of a high-fat diet. Sudden increases in fat content of a horse's diet can lead to poor digestibility of fats and gastric upset (Pearson 2015).

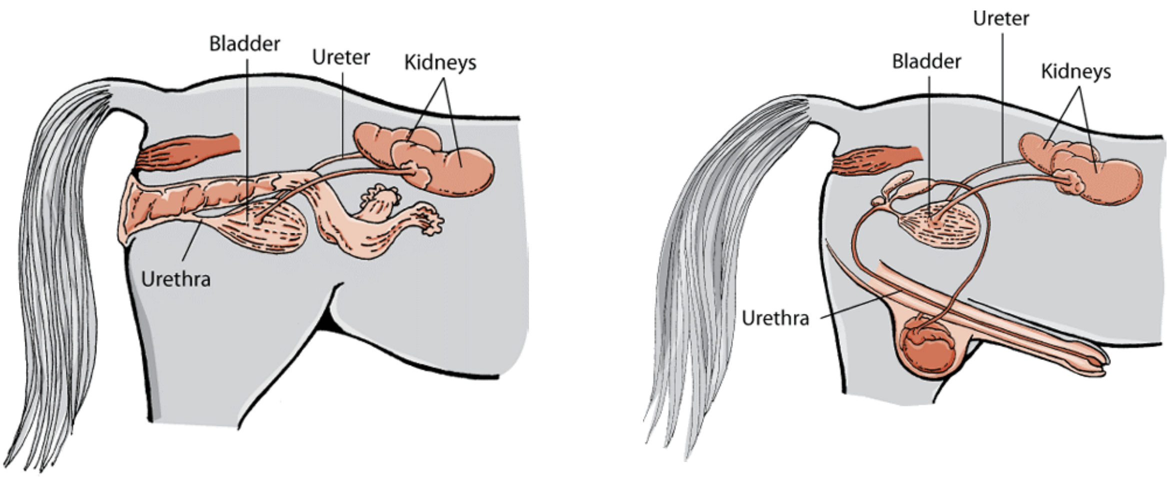


In addition to facilitating digestion, the liver also is the primary site for the process of gluconeogenesis in which glucose is generated from certain non-carbohydrate carbon. It also provides a storage for fat-soluble vitamins such a A,D and E. The liver is a major storage site for glycogen which is key in providing energy for the exercising horse.

KIDNEYS

The kidneys are part of the urinary system of the horse.

Situated on either side of the spine, just beneath the last few ribs[6], the equine kidneys function very much like a waste-water treatment plant. The right kidney lies to the sacrum whereas the left one lies to the psoas and diaphragm. Protected from impact and injury by a cushioning layer of fat, fascia, muscles and bone, the kidneys sort through the various substances carried in the blood, conserving those that the horse needs and disposing of those that could do harm. The kidneys are extremely efficient in their job, processing every drop of blood twice per hour. The entire blood volume (on average, about 9 gallons) passes through the kidneys more than 60 times in 24 hours. Therefore, the kidneys prove the be amongst the most reliable of all the regulatory systems.



Pictures adapted from Merck Veterinary Manual 2019 illustrating the urinary systems of a mare and a stallion/gelding.

As the kidneys carry out their basic filtration duties they also monitor and regulate fluid volume and composition. Furthermore, they promote red blood cell production, modulate blood pressure and control the blood's pH (acidity) and the body's electrolyte balances. Specifically, the kidneys closely regulate the body's salt balance. Any extra salt is excreted

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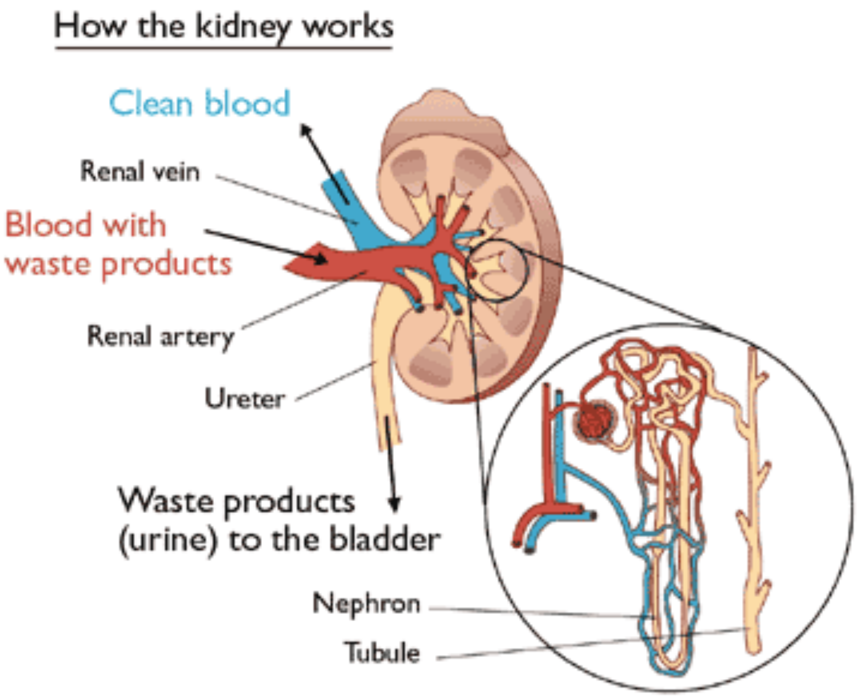
[6] *Because of this location a floating rib can interfere with kidney function.*

while necessary salt and fluid are returned to the bloodstream along with valuable materials such as mineral electrolytes and sugars.

Blood arrives in the kidneys via the renal artery--a branch of the aorta--and is processed in two layers of kidney tissue that lie beneath the organs' covering. Within the tissue, more than a million microscopic filtering units called nephrons handle the purification duties. These nephrons are the structural and functional units of the kidneys and are composed of:

- **A renal corpuscle** → Consist of a tuft of capillaries called a glomerulus and an encompassing Bowman's capsule. The glomerulus filters the blood
- **Renal tubule** → Extends from the Bowman's capsule. The tubule returns needed substances to the blood and pulls out additional wastes. These wastes and extra water become urine.



Only about 25 to 30 percent of the nephrons actively process fluid full-time. The remainder stand by in case of an increase in blood flow, which may be triggered by illness, excitement or cold temperatures. Additional nephrons also may be called into service when a horse consumes more water than usual.

The nephrons work though a four-step process:

Filtration → Reabsorption → Secretion → Excretion

The process starts with the mass movement of water and solutes from blood to the renal tubule that occurs in the renal corpuscle. The filtration process is primarily driven by hydraulic pressure (blood pressure) in the capillaries of the glomerulus. About 20% of the blood plasma volume passing through the glomerulus at any given time is filtered. Those molecules of protein, fats and blood cells that are too large to fit through the filters of the Bowman's capsule are rejected and remain in the circulation for other destinations.

The filtered fluid then flows from the Bowman's capsule into the kidneys tubules through a long winding tube called the 'Loop of Henle. Important materials passing through these filters – such as salt, potassium, sulphate, phosphate, sugars, amino acids and nitrogenous wastes – are being sorted. What is needed by the body gets extracted and returned by the blood to replenish deficits. What is harmful or excessive must be removed.

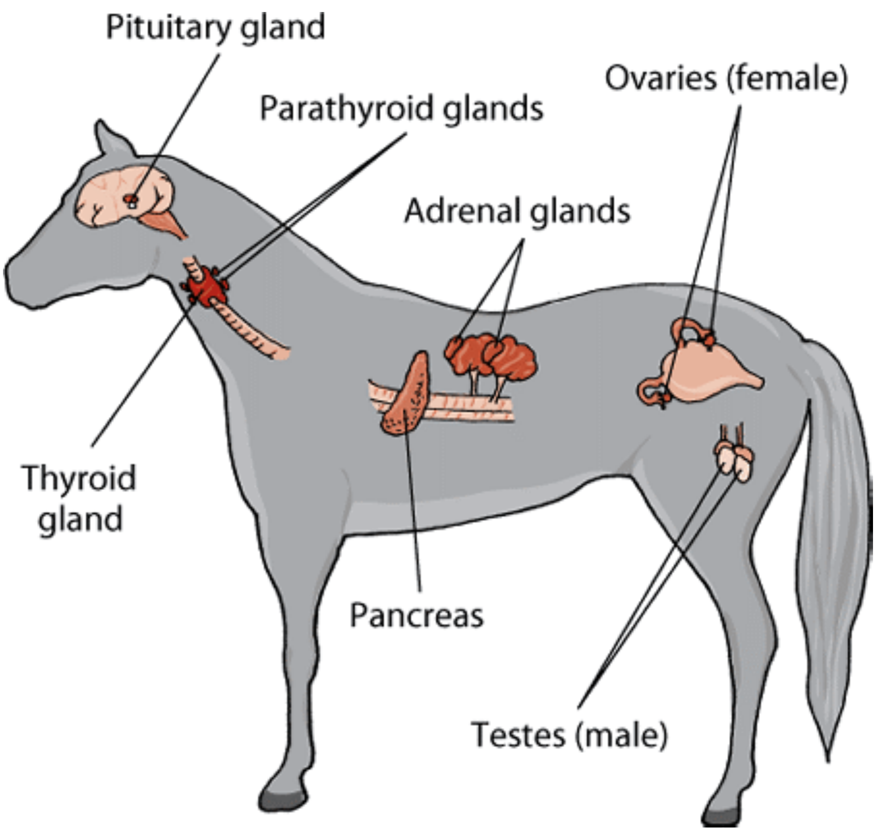
Even after the filtration and reabsorption processes, the tubules continue to secrete additional substances into the tubular fluid. This enhances the kidney's ability to eliminate certain wastes and toxins. It is also essential to regulation of potassium concentrations and pH balance.

Finally, the remaining wasted will be concentrated into urine. Excretion is what goes into the urine and therefore the end result of the above three processes. The kidneys filter much more fluid than the amount of urine that is actually excreted as the original volume of the tubule fluid is dramatically altered by the processes of reabsorption and/or secretion.

Any potential waste that proves too large to fit through the kidneys' tubes is rerouted to the liver or the gut wall, where it is processed for excretion with solid faeces.

ADRENAL GLANDS

The adrenal glands are small organs situated on top of both kidneys and is part of the horse's hormone management – the endocrine system.



Picture adapted from Merck Veterinary Manuals (2019) illustrating the major endocrine glands in the horse.

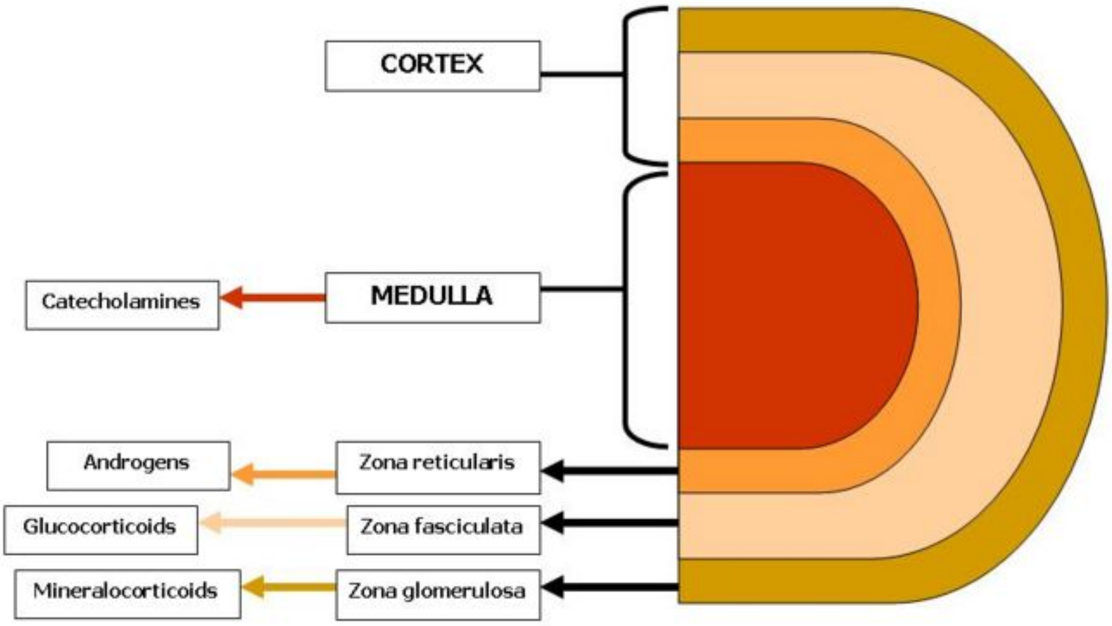
The adrenals play in important role in the production of various hormones. The adrenals glands can be divided between the cortex and the medulla. The adrenal cortex consists of three layers, each of which produces a different set of steroid hormones:

- **Zona Golmerulosa** → The outer layer produces the mineralocorticoids which help to control the body's balance of sodium and potassium salts.
- **Zona Fasciculata** → The middle layer produces the glucocorticoids which are involved in metabolizing nutrients as well as reducing inflammation.

- **Zona Reticularis →** The inner layer produces the androgens – otherwise referred to as sex hormones – such as oestrogen and progesterone which play an important part in the procreation process.

The adrenal medulla plays an important role in response to stress –hence it's nickname as the 'shock organ' - of low blood sugar (glucose). It releases epinephrine – adrenaline – and norepinephrine, both of which increase heart output, blood pressure, blood glucose and slow digestion.

The lymphatic network within the adrenal glands drains into the lumbar aortic lymph nodes.



PANCREAS

The pancreas is located in the abdominal cavity, near the start of the small intestine and below the kidney. It plays a role in the horse's metabolism by producing digestive enzymes, but the organ is mostly known for its involvement in the production of the hormone insulin and thus the disease such as Equine Metabolic Syndrome (Insulin resistance). Hence – the ancient Greeks referred to it as the 'stomach sweetbreads'.

The pancreas consists of hormone producing cell clusters called Islets of Langerhans which contain three different kind of cells each which produces a different hormone:

- **Insulin →** most of the beta cell. Insulin affects, either directly or indirectly, the function of every organ in the horse's body, particular the liver, fat cells and muscle. It is the primary modulator of blood-sugar (glucose) concentration, acts swiftly after food intake to limit the liver's production of glucose and increase stored energy (glycogen) in that organ, to facilitate increased protein synthesis, to convert un-needed energy to fat for storage in body tissues and possibly to control appetite.
- **Glucagon →** Insulin and glucagon work together to keep the concentration of glucose in the blood and other body fluids within a relatively narrow range. Glucagon raises blood sugar level by controlling glucose release from the liver.
- **Somatostatin →** found in the delta cells. Inhibits insulin and glucagon secretion. It affects neurotransmission and cell proliferation. In the stomach, somatostatin acts directly on the production of acid.

CONCLUSION

Woohoooo! By now you've made it through ☺️ Fascinating isn't it? Although a bit complicated and maybe dry matter, I hope you have gained a bit more insight into the fascinating being of your horse. It is now time to explore how anatomy affects movement – biomechanics which will be covered in the next video series and manuals. But first:

Go out, give your brain some rest and have a great time with your horse☺️

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