UNIVERSIDADE LUSÓFONA

CICANT

Basic equine locomotion characteristics,

morphologic and anatomical references

TECHNICAL REPORT

EQUIPERFORM

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EquiPerfoRM

Three-dimensional motion analysis for monitoring of rehabilitation and high-performance training of the equine athlete.

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A THREE-DIMENSIONAL EQUINE MODEL

Equine locomotion characteristics, morphologic and anatomical references

Índice

I - EQUINE LOCOMOTION CHARACTERISTICS

This technical report is intended to support members of the EQUIPerform project team who are not Veterinarians. Therefore, the characteristics of some types of locomotion are briefly described.

The horse can use several gaits or "patterns of limbs movement" during locomotion in solid ground. Generally, in this report, the term "movement" will be used as the meaning of any type of locomotion. Some movements are innate to the horse's motor development, other movements are the result of learning conducted by humans. The horse has four natural modes of locomotion - Walk, Trot, Canter and Gallop - and several specialized alternatives based on performances that change the type and number of beats on the ground in each cycle. Their spatial-temporal characteristics during locomotion associated with the speed of the horse. The movements found in the different horse breeds are the step, the Trot, the canter, and then Walk, a type of non-classical Walk [1; 2; 3; 4].

However, following the aims of the project EQUIPerform, the only focus will be centred in two movements, the Walk and the Trot, as mentioned immediately in the initial summary: " … Data describing the horse spatial-temporal and angular kinematic parameters within a complete Walk and Trot stride will be analysed and include the stride length, stride duration, stride speed and maximum, minimum and range of motion of each joint and its peak values….".

Despite the attention about Walk and the Trot, the four natural modes of locomotion must be remembered. To increase its speed, the horse can alternate its movement from **Walk** to **Trot**, from Trot to canter, and then extend the canter. Each stroke can be extended, changing the spatial and temporal characteristics of your movements. Ponies have been shown to have a preferred speed for the transition from Trotting to canter and that speed was related to an optimal metabolic cost of running5a;6a. However, another study demonstrated that the transition from Trotting to canter was triggered when the peak reaction force on the ground reached a critical level of about 1 to 1.25 times the animal's body weight[7; 6].

To increase the speed in each movement, the amplitude of the steps becomes larger and the duration of the limb cycle is reduced to repeat the movements of the limbs more frequently. Stride frequency (SF) and stride length (SL) are the two main components of speed. The average speed can be estimated by the product of the multiplication of the stride frequency and stride length: Speed: SF x SL[6].

Speed-related changes have been studied in many horse breeds and modalities. The stride length increases linearly with the speed of travel, while the stride frequency increases nonlinearly and more slowly[16;3;10;6]. During rapid acceleration, as at the beginning of a canter run, the stride frequency reaches its maximum value very quickly to produce the initial acceleration, while the maximum stride length increases more slowly to its maximum value[11; 6].

Overview of Walk and Trot characteristics

The main purposes of the analysis of movements in horses are, to describe normal locomotion, characterize the abnormal movement and evaluate sports performance. New techniques are developed aiming at the prevention of locomotor disorders, the formation of a

database to provide information that allows the quick recovery of the animal, the improvement of athletic performance and the selection of horses with an aptitude for a sport.

The process of moving forward or the body is conceived as the process of normal locomotion and a functional task that involves complex and simultaneous interactions of the organic structures responsible for the nervous system and the locomotor system [12;13;14;15;16], generating structural movements for analysis and interpretation [13;17;16]. The animals determine the Walking pattern that optimizes the economy or energy consumption for each Walking speed [14; 16].

Equine limbs form a perfectly harmonic set with the active participation of each component, both anatomically and functionally. The horse's body has the skeleton as a framework, which is the foundation for the lever system with a fulcrum in each joint. The tendons act as transmitters of the kinetics of muscle contraction, allowing the movement of all the structures that form and maintain joint stability. Under the command of the central nervous system, the horse's structural and functional complex, made up of skeletal muscles, is dependent on the cardiovascular and respiratory systems and can perform naturally and instinctively, or under conditioning, movements such as flexion, extension, adduction, abduction and rotation depending on the type of joint. It is through the combination of each of these movements that the horse can move in the most varied ways and submit to the conditions of physical effort required, particularly in sporting situations[7].

The horse's locomotion[6] could be defined as a complex and strictly coordinated, rhythmic and automatic movement of the limbs and the entire body of the animal, which results in the production of progressive movements. In horses, a pace of two, three or four ground beats corresponds to the number of steps that can be heard during each step of each type of locomotion. The sounds of ground beats are related to the stepping pattern during Walking. However, when the interval between steps is noticeably short, the human ear is not able to differentiate it. Thus, locomotion classification methods depend on the symmetry between the left and right sides. In a symmetrical face, the steps on the left and right sides of the thoracic and pelvic limbs are eventually spaced in time, while in an asymmetric Walk, the steps of the thoracic and pelvic limbs occur concurrently.

Walk characteristics

Walk is a type of natural gait, which can also be artificial, symmetrical, lateral, and diagonal in four steps. Their movements and supports, like the step, are of the lateral and diagonal bipeds interspersed with tripedal supports due to the dissociation of the limbs. Their reactions are extremely smooth, with a little displacement of the center of gravity. The stride length is close to 2.0 meters and the speed between 12 and 14 km/h[18].

The Walk brings together a high performance (characteristic of the Trot) with high convenience and comfort to ride (characteristic of Walking) without, however, presenting moments of suspension[19; 20; 21; 22]. The is a dissociated pace so that each member is at a different time from the phases of support, elevation and advance in the path taken by the member.

Desta forma, a duração das fases de apoio e elevação e cada membro não é a mesma, bem como, para os pares de membros em deslocamentos laterais e diagonais [21; 18; 23], conforme mostra a figura1.

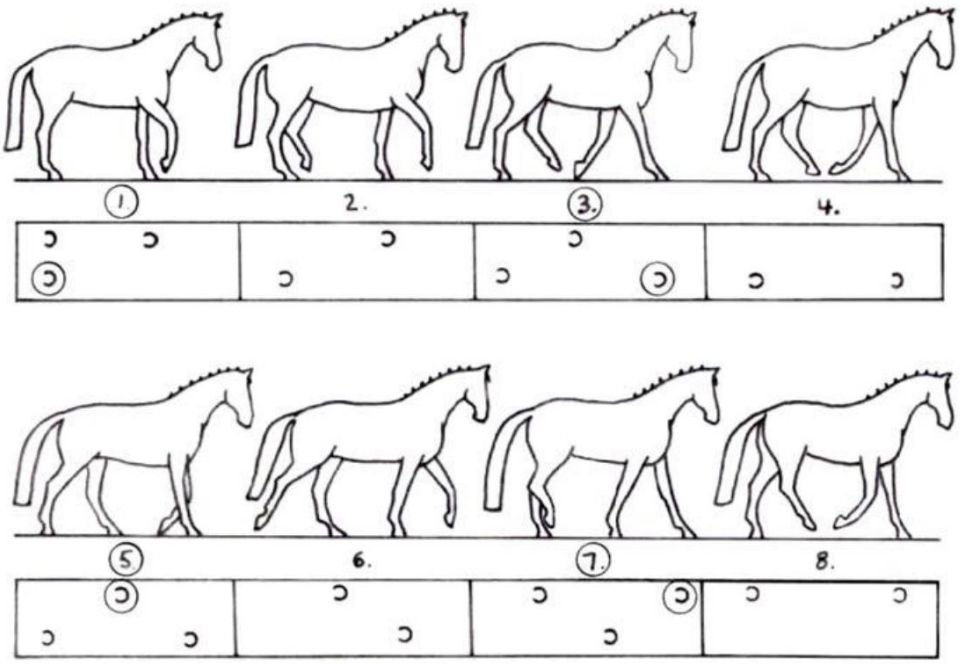

Figure 1: The horse's Walk. Adapted from Hussni et al. (1996) *Sequence of distribution of supports of the ground beat In Walk beat, it is observed whether the bipedal and diagonal supports interspersed by moments of triple support.*

In effect, the result of this dissociation is greater, if not constant, contact of the animal with the ground through the limbs, which does not occur in the Trot that alternates moments of support and complete suspension. This constant contact with the ground is responsible for the softness and comfort of the riding horse[24;22].

The chopped Walk was defined as asymmetrical 4-step Walk, with 8 moments of support[25], called gait itself[26] for presenting moments of triple support interspersed with defined lateral bipedal supports[27; 28; 29; 30]. In this type of movement, there is a predominance of lateral displacements [30], that is, members on the same side of the body, with a longer elevation of the forelimbs, which reduces the performance of the strides, since the horizontal advancement of the limb is impaired to the detriment of vertical displacement[20; 21].

As it is a 4-stroke movement, due to the high degree of dissociation present in this type of Walking, the hitting of the hooves on the ground also occurs in four moments. As a result of this completely dissociated displacement, the diagram of the chopped gait follows the same diagram as the step, so each beat of the hooves on the ground is heard separately, which in general leads to a "*taca-taca-taca*" sound [32]. Triple supports are greater than 20% of the stride duration, with no single limb supports[22].

It is an intermediate movement to the beat and prick marches, with dissociation between the diagonal and lateral members, in such a way that a predominant member is not identified during the movement. The proportion between diagonal and lateral supports is the same so that there is a regular and well-defined frequency of triple supports. It has 4 times in 8 moments and a sequence of supports identical to that of step- four triples, two diagonal bipedals and two lateral bipedals[22].

The Trotted Walk is a movement with 2 strokes and 6 moments of support[26]. It would be asymmetrical two-stroke[25] close to the beaten gait, but without lateral bipedal supports,

which are replaced by single-legged, posterior and anterior supports[28; 29]. The dissociation in this gait is much less than in the others, which brings it closer to the Trot, being by some authors called the Trotting march [33]. However, it does not have a total suspension of the four limbs, which does not classify it as a hoax. The proportions of triple supports are less than 20% of the total stride duration time, and the lateral supports, less than 5%[22]. It is a pace that has comfort, without loss of balance, maintaining agility, since the amplitudes of movements of the posterior and anterior strides are equivalent[33].

Trot characteristics

The Trot is a natural, jumped motion, because from raising to supporting a certain associated diagonal member, there is a suspension time, that is, a moment when the horse is completely in the air, without any support to the ground, symmetrical due to the symmetry of the column movements with its longitudinal, diagonal and two-stroke axis. Their movements and supports are diagonal interspersed with moments of suspension when exchanging limbs[34], as shown in figure 2.

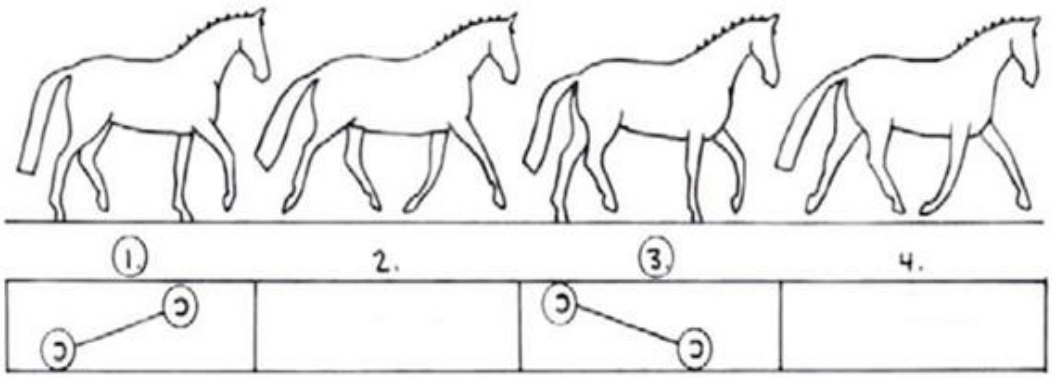

Figure 2: The horse's Trot. *Adapted from Hussni et al. (1996) Sequence of distribution of supports of the ground beat In Walk beat, it is observed whether the bipedal and diagonal supports interspersed by moments of triple support.*

In ascending order of speed, the next (natural) pace after the step is the Trot. The Trot is a two-stroke, with a wide range of speeds, but that, on average, revolves around 13 km / h[35]. It is another symmetrical movement in which the animal has two diagonal support phases and two suspension phases[36].

Unlike the step, in the Trot the result of the symmetry is that the pairs of diagonal limbs move in the same time interval, which results in the association of these limbs[37; 38; 39; 40], giving this movement great stability[17; 22]. Like the step, the Trot is also driven by the posterior train, if the movement starts with the left posterior limb, a possible sequence of movements would be: right pelvic limb - left thoracic limb, suspension, left pelvic limb- right thoracic, suspension[41].

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II - MORPHOLOGIC AND ANATOMICAL REFERENCES

Anthropometric characteristics of Portuguese horse breeds: "Puro Sangue Lusitano", "Alter Real", "Sorraia" and "Guarrano";

In general, horses are selected through the evaluation of morphological parameters related to their similarity with the breed standard. The most relevant aspects that are considered are, above all, the morphology with particular care for the morphological parameters related to the "Head" and "Neck", "Pectoral", "Forelimbs and Hindblimbs" and, "Height at withers". Therefore, there is an effort and a commitment on the part of the breeders for the development of these parameters, to improve the morphology of the horse, as well as its functionality for various activities that will be used[1].

The main morphological parameters to be evaluated in the horse are[2; 3; 4; 1;5]:

1. Height at the withers - the vertical distance from the highest point of the interscapular region, located in the space defined by the spinous process of the 5th and 6th thoracic vertebra, to the ground.

2. *Height at the croup* - the vertical distance from the highest point of the croup, more specifically over the sacral tuberosity, to the ground.

3.*Body length* - distance from the cranial face of the greater humerus tubercle to the caudal end of the ischial tuberosity.

4. Neck length - distance from the cranial portion of the lateral aspect of the atlas wing to the midpoint of the cranial edge of the scapula.

5. Scapular-billet distance - distance from the central area of the scapular-humeral joint to the middle third of the face of the lateral side of the metacarpophalangeal joint of the left thoracic limb.

6. length of the forearm - distance from the central area of the humerus-radial joint to the lateral middle third of the carpal joint.

7. Thoracic shin-length - distance from the lateral middle third of the carpal joint to the middle third of the side of the lateral side of the metacarpophalangeal joint of the left thoracic limb.

8.Length of the chest wall - distance from the middle third of the lateral face of the metacarpophalangeal joint to the lateral face of the proximal interphalangeal joint of the left thoracic limb.

9. Limb length - distance from the lateral midpoint of the femoro tibio patellar joint to the lateral middle third of the tarsal joint.

10. Pelvic shin-length - distance from the lateral middle third of the tarsal joint to the middle third of the lateral aspect of the metatarsophalangeal joint of the left limb.

11. Pelvic quarter length - distance from the middle third of the lateral face of the metatarsophalangeal joint to the lateral face of the proximal interphalangeal joint of the left thoracic limb.

There are four indigenous breeds of horses officially recognized in Portugal, they are the "Garrana" breed, the "Sorraia" breed, the "Puro Sangue Lusitano" breed and the "Alter Real" breed. Of these four breeds, the Lusitano horse is the most emblematic breed in Portugal[6], has adopted its name from the name attributed to Portugal in antiquity, "Lusitânia"[7].Thus, the

Lusitano Thoroughbred horse that has been ridden for more than 5,000 years, has been recognized, since antiquity, as the best saddle horse in the world, having stood out particularly during the Greek and Roman eras[8], as shown in table 1.

Table 1: *Morphological characteristics of the Puro Sangue Lusitano breed*

Height and Type	Eumetric or, well proportioned, Weight about 500Kg, Mediolanum, sub-convex (rounded), with a silhouette inscribable in a square. Average withers, measured with a hygrometer, at 6 years: females 1.55 m, Males 1.60 m.
Head	Well proportioned, of medium length, thin and dry, with a little developed mandibular branch and relatively long faces, with a slightly sub convex profile, slightly arched forehead (protruding between the supraciliary arches), eyes on the elliptical, large and alive, expressive and confident. The ears are medium in length, thin, slender and expressive
Neck	Of medium length, rotated, with a thin mane, with a narrow connection to the head, wide at the base, and well inserted in the shoulders, leaving the withers without accentuated depression.
"Garrote"	Well highlighted and extensive, in a smooth transition between the back and neck, always slightly higher than the croup. In whole males, it is drowned in fat, but it always stands out well from the shoulders.
Breastplate	Of medium amplitude, deep and muscular
Back	Well developed, extensive and deep, ribs slightly arched, inserted obliquely in the spine, providing a short and full flank.
Shoulder	Long, oblique, and well-muscled.
Croup	Strong and rounded, well proportioned, slightly oblique, of identical length and width, with a convex, harmonic profile, and little evident hip tips, giving the croup an elliptical cross-section. Tail coming out following the curvature of the rump, silky mane, long and abundant.
Forearms and Hindlimbs	Well-muscled arm, harmoniously inclined. Well, muscular forearm. Knee dry and broad. Cinnamon on the long, dry and with well-detached tendons. Dry boletus, relatively bulky, and almost without mallets. Relatively long and oblique quarters. Hooves of good constitution, well-shaped and proportioned, of beads not open and crown not evident. Buttock short and convex. Muscular thigh, over the short, directed so that the kneecap is located vertically at the tip of the hip. The leg on long, placing the tip of the hips vertically from the tip of the buttock. Wide, strong, and dry hunchback. Hind members have relatively closed angles.

Source: Associação Portuguesa de Criadores de Cavalos Puro-sangue Lusitano (APSL)

The “Garranos” are animals of small stature (height at withers below 1.35 m), weighing approximately 290 kg, with a straight or concave head profile, with a large and thin head, especially in males, where large nostrils stand out. Being a small horse, it presents a solid structure and a short pace, transmitting high security, typical of an animal used to face steep and stony paths9, as shown in table 2.

Table 2: Morphological characteristics of the Garrano breed

Height and Type	
Head	Type - Hypermetric (weight about 290 kg) and medium-sized. Height - Measured at withers, with a hypo meter, in adult animals (3 years for females and 4 years for males). The maximum allowed - 1.35 m. Average: Females: 1.28 m Males: 1.30 m
Neck	Straight profile, sometimes concave, the latter being characteristic of its ethnic purity. Thin but vigorous head. The skull is always inserted in the face with a great inclination so that the upper part of the forehead is convex in profile, the occipital crest is not very prominent to the condyles. Protruding orbits across the forehead, transversely flat. The eyes are round and expressive. Wide nostrils. Medium ears. The teeth are characteristic. Hooks are strong and muscular.
“Garrote”	Well driven and muscular, but short and thick, especially in the stallions
Breastplate	Low, but prominent, with smooth transition between the neck and the back.
Back	Medium in size and muscular
Shoulder	Well directed, tending towards the horizontal.
Croup	Vertical and short
Forearms and Hindlimbs	Strong, rounded, and wide, tending towards the horizontal, of identical length and width.

Source: Percurso do Homem e Garrano

The Sorraia breed has a small size - the average height at withers of 1.48m for males and 1.44m for females - it is considered a true horse, characterized by a conformation of the metric and medium type and subconvexylinous[10;11;12]. The primitive character of this breed is its rusticity and unusual ability to survive in extreme conditions, as well as the results obtained at the molecular level. Used as saddle horses and for varied agricultural work, they remained for many years relegated to total abandonment by their breeders, enduring the scarcity of food and living outdoors day and night, exposed to all types of weather[10;11;12;13] , therefore table 3 presents the morphological.

Table 3: Morphological characteristics of the Sorraia breed

Height and Type	Measured with a hygrometer in adult animals: Males: 1.48m Females: 1.44m Not the average body mass record in this breed.
Head	Rectangular and dry, with sub convex profile, skull sharply inclined with the face, which is quite long. The expressive eyes, inserted in an elliptical orbit truncated posteriorly and located above the occipital-incisor line. The ears are long, dry and mobile, with delayed implantation due to the inclination of the skull
Neck	Slender, of medium length, inverted in lean animals, stores fat for the time of hunger, causing it to transform and appear rotated in the fat animal.
"Garrote"	Well highlighted and very extensive, it is connected almost to the middle of the back by a smooth line.
Breastplate	Not too broad but muscular. The cilhadouro is well situated under the saddle. The chest is deep and not too wide.
Back	It is extensive and composed of flat, long ribs that well support the flank. It is short, horizontal and detached from the ribs.
Shoulder	Of medium length, they are dry and relatively oblique.
Croup	Medium in width and length and elliptical in shape, showing the prominent sacred crest with a sub convex profile.
Forearms and Hindlimbs	Forelimbs: Slight bone, but well-rounded. Arms harmoniously tilted. Forearms well erected and not very muscular. Knees well shaped, dry and not bulky. Slightly long, dry shins, with prominent tendons with no overlapping hair. Light bulky boletus, almost without mallets Quarters on the long and harmoniously inclined. Well-shaped and upright hooves, with a light appearance and good quality mud. Hind limbs: Slight in bone and musculature, but well-shaped. Well shaped curves. Shins, boletus, barracks and hooves as of the forelimbs.

Source: Associação Internacional de Criadores de Cavalos Ibéricos de Tipo Primitivo - Sorraia

The "Alter Real" horse is a medium-sized and straight animal, with an average weight from the age of four that is around 450-500 kg as well as a height of 1.52 m at the withers for mares and 1.54 m for horses. The standard predicts that the animal can grow up to 1.62 m. Due to its rusticity and versatility, it is an animal admirably adapted to all climates and, not only fit but good, in all terrains and equestrian modalities. It has a rectangular head, of medium length and with a sub-convex profile, a well-detached tourniquet accompanied by a well-developed trunk, slightly rounded side, and broad chest Monteiro14. Table 4 presents the morphological characteristics of this breed.

Table 4: Morphological characteristics of the Alter Real breed

Height and Type	Measured with a hygrometer in adult animals: Males: 1.48m Females: 1.44m Not the average body mass record in this breed.
Head	Rectangular and dry, with sub convex profile, skull sharply inclined with the face, which is quite long. The expressive eyes, inserted in an elliptical orbit truncated posteriorly and located above the occipital-incisor line. The ears are long, dry and mobile, with delayed implantation due to the inclination of the skull
Neck	Slender, of medium length, inverted in lean animals, stores fat for the time of hunger, causing it to transform and appear rotated in the fat animal.
"Garrote"	Well highlighted and very extensive, it is connected almost to the middle of the back by a smooth line.
Breastplate	Not too broad but muscular. The cilhadouro is well situated under the saddle. The chest is deep and not too wide.
Back	It is extensive and composed of flat, long ribs that well support the flank. It is short, horizontal and detached from the ribs.
Shoulder	Of medium length, they are dry and relatively oblique.
Croup	Medium in width and length and elliptical in shape, showing the prominent sacred crest with a sub convex profile.
Forearms and Hindlimbs	Forelimbs: Slight bone, but well-rounded. Arms harmoniously tilted. Forearms well erected and not very muscular. Knees well shaped, dry and not bulky. Slightly long, dry shins, with prominent tendons with no overlapping hair. Light bulky boletus, almost without mallets Quarters on the long and harmoniously inclined. Well-shaped and upright hooves, with a light appearance and good quality mud. Hind limbs: Slight in bone and musculature, but well-shaped. Well shaped curves. Shins, boletus, barracks and hooves as of the forelimbs.

Source: Fundação Alter Real

Overview of the Equine Locomotor System

Skeletal System

The skeletal system is responsible for forming the structural and support of horses and consists of 205 bones: 54 spinal vertebrae, 36 ribs, a sternum, 34 cranial bones, 40 bones that make up the thoracic limbs and also 40 bones that make up the pelvic limbs. Specifically, the thoracic limbs are composed of the proximal to distal aspect in the scapula, humerus, radius, ulna, carpal bones, metacarpal bones, proximal phalanx, middle phalanx, and distal phalanx. The pelvic limbs, on the other hand, consist of the bones of the femur, patella, tibia, fibula, tarsal bones, metatarsal bones, proximal, middle, and distal phalanges. The pelvic framework is extremely important for locomotion and its constituents are the ilio-ischium-pubic junctions, the sacrum and the first three caudal vertebrae[17].

Joints are structures that allow mobility between distal and proximal bone structures without wearing them out, while ligaments are structures of connective tissue that guarantee the connection between bones with limited mobility. In the case of horses, the scapular-humeral joint contains a capsule and two glenohumeral ligaments, which guarantee structural reinforcement and limit movements of 80 ° of flexion and 145 ° of extension. The elbow joint has the shape of a hinge and as a reinforcement, it has the collateral, medial and lateral ligaments, which in turn, limit the extension in 60 ° of amplitude and the flexion in 150°[17].

The carpus consists of seven to eight carpian bones, in the orthostatic position they are in extension, formed by the antebraquicarpica, intercarpal and carpometacarpal, lined with the joint capsule and synovial membrane, stabilized by carpal palmar ligaments, extensor retinaculum (carpal dorsal ligament) and ligaments collateral, lateral and medial. Below the carpus is the metacarpophalangeal joint, which also has a hinge shape and is reinforced by the collateral and sesamoid ligaments. Proximal interphalangeal joint consists of the articular capsule, collateral, and palmar ligaments and in orthostasis, is in extension and allows a small palmar flexion. Finally, there follows the distal interphalangeal joint also equipped with a joint capsule, collateral sesamoid ligaments, and unique angular-sesamoid ligament, performing flexion and extension[17].

The pelvic limb presents the sacroiliac joints reinforced by the ventral, dorsal, wide sacrotuberous and iliolumbar sacroiliac ligaments that guarantee pelvic stability. The hip joint is of the spheroidal type with a spacious joint capsule and synovial membrane, in addition to being constituted by the transverse ligaments of the acetabulum, the head of the accessory femur of the femur. As it is spheroidal, it allows movement in all planes, and in an orthostatic position, it is flexed at 115º[17].

The knee joint is formed by the femorotibiopatellar joints, which have a thin and expanded joint capsule, in addition to the femoropatellar (lateral and medial), patellar (lateral, intermediate and medial) ligaments and the femorotibial joint, which in addition to the joint capsule is composed of menisci that favour shock absorption during gait and meniscus ligaments caudal and cranial (lateral and medial), collateral (medial and lateral) and crossed (cranial and caudal) and transverse knee ligament, which allow 150º angulation inflexion. The tarsal junction is a complex structure formed by talocrural joints, intertarsal and tarsometatarsal joints; by synovial sacs and a weave of ligaments that allow an articular angle of 150 ° in an orthostatic

position, and flexion will be prevented only by the contact of the metatarsus with the leg, as shown in figure 3[17].

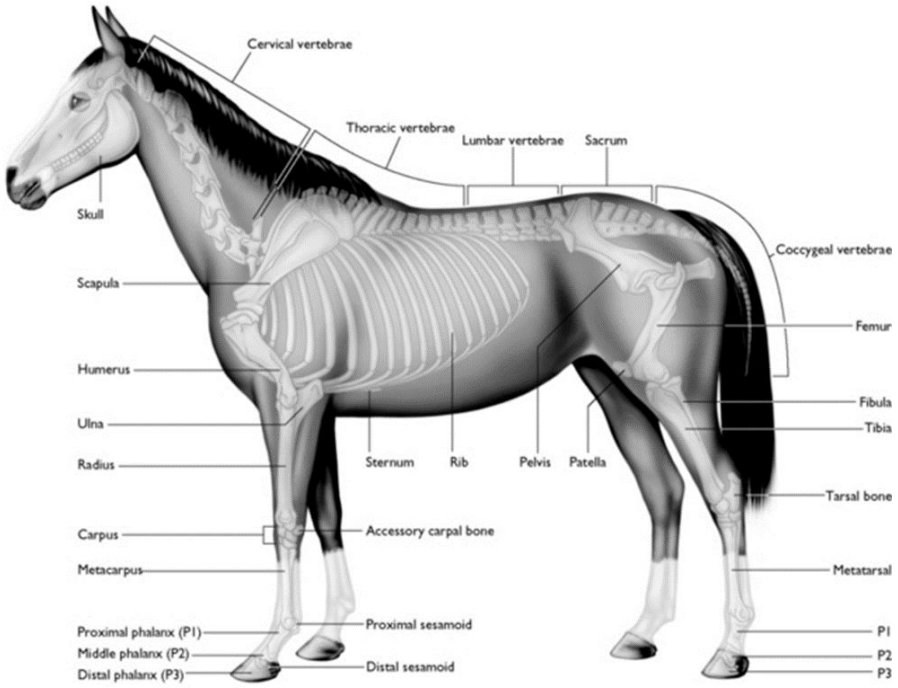

Figure 3: Equine Skeletal Sche. Adapted from Aspinall's Complete Textbook of Veterinary Nursing, 3rd

In general, several muscle groups cover these bone and joint structures and are solely responsible for the movement of the body. Depending on their origin and insertion, the muscles exert flexion, extension, rotation, adduction, and abduction[17].

The knowledge of the nomenclature of the external parts of the horse's body, the zootechnical terms, are also important, because, in practice, it is the most used name and are related to some anatomical structures previously described[17].

In the head region, the nape is the region that corresponds to the caudal portion of the skull and the first cervical vertebra; the forehead correlates with the frontal bone region; chamfer is the sinusoidal region that extends from the forehead to the nostrils, and the hook corresponds to the jaw. In the thoracic limbs, the pectoralis the region of the pectoral muscles; the elbow is known as codilho; billet comprises the metacarpophalangeal joint; quarter corresponds to the proximal and middle phalanges; on the caudal face of the limb there is a belt that corresponds to the cranial and ventral part of the trunk; chestnut is a set of undeveloped corneal formations, and macho, corneal formations after the billet[17].

The withers are found on the back of the horse, a space between the scapulae after neck; the back comprises the most bulged region of the trunk, which precedes the loin; and the croup, the region between the loin and the tail; the flank is located on the caudal side of the trunk and is completely covered by muscles; the hip comprises the region between the flank and the thigh. In the pelvic limbs, unlike the thoracic limb, there is the thigh, the leg, the weld and the hock, the hock region[17].

Joint System

The joints of the horses are responsible for the movement next to the skeleton. The joints are formed when one or more bones are joined and are classified as fibrous, cartilaginous, and synovial, the latter being of greater importance[18].

The fibrous joints present the bones connected by dense connective tissue and have little mobility; cartilaginous joints connect bones through cartilage, allowing few and limited movements; and the synovial joints connect the bony extremities through a cavity filled with fluid (synovial fluid) and allow maximum movement[19].

The synovial joint has great stability and prevents abnormal movements from being performed, reduces impacts during physical activities, facilitates mobility and makes friction between bones practically non-existent due to the synovial membrane that protects the bony extremities. This membrane produces synovial fluid that has a lubricating function in the joint, and this is responsible for preventing friction and preventing wear of the joint[20].

From the anatomical point of view, synovial joints are classified as mobile, allowing the displacement of bone in three dimensions: flexion and longitudinal extension comprising the sagittal plane, lateral flexion comprising the frontal plane, and rotation movements. The direction of these movements depends on the shape of the articular surfaces[18].

Thus, the ideal locomotion of horses occurs when there is no restriction of movement in the joints, that is, when there are perfect contraction and relaxation of the muscles associated with certain joints, such as, for example, the lumbosacral joint (L6-S1)[21]. This joint is responsible for the pelvic tilt and collaborates with the protraction and retraction of the limbs21. At the point where the spine connects with the pelvis is the sacroiliac joint, it is here that the transfer of the propulsion forces established by the posterior member to the spine occurs[22].

Therefore, movement restriction contributes to changes in the joints, impairing their functionality and being able to promote the development of asymmetric movements[21]. Thus, joint stability, limb movement, posture and locomotion depend on muscle activation.

Body movements, that is, forward, sideways, backward, or even movements without changing location, are the result of coordinated movements of individual body parts[18]. These movements depend on functional groups of muscles, as in the locomotion of horses in which the limbs are moved due to the activation of these muscles[22].

Muscular System

The horse's muscles consist of muscle masses attached to the bones on the one hand and the tendons on the other. The tendons are protected by synovial sheaths that are made up of thin and fibrous films and that protect the tendons from the risk of friction with the bone[19].

Ligaments, like tendons, are relatively short, as are joint reinforcers. However, there are special ligaments: the restrictor, which attaches to the ligament behind the knee joint and joins the deep digital flexor tendon in its lowest part behind the shin bone; and the hanger, which has the upper end connected to the upper back part of the shin and in the lower row of the knee bones, the lower end connected to the sesamoid, under the billet. This system is similar in the anterior and posterior members[19].

To maintain or improve the physical shape of the animal, the ideal is to work it constantly. The movement of muscles during training causes the diameter of muscle fibres to increase, thereby increasing the animal's power[19].

Anatomy of the Horse's Hoof

The structures that form the anatomy of the hoof are wall, sole, groove and bulb. The visible tissue, when the animal is in a quadrupedal position, is a wall or hoof wall, which is divided into forceps, quarters, and beads[23]. The composition of the hull wall is, from the outside to the inside, external layer, medium layer, and internal layer. The outer layer is the thinnest and is formed by keratinized cells that leave the hull wall with a shiny and smooth appearance this more superficial layer extends distally towards the perioplo[23].

The middle layer or middle layer is the thickest layer of the three layers and is differentiated by its tubular structure. It is the main structure that assists in the load support, serving to absorb the reaction force from the soil to the equine skeleton. Its anatomical architecture gives it resistance during movements. Keratin is the main protein present in the horny case, skin, hair, horns, and claws. Such protein can be grouped in hard, rich in disulfide bridges bringing a presentation of great physical strength; and the soft, rich in sulfhydryl groups and poor in disulfide bridges, being less resistant. The perioplo, the ranilha, the bulb and the white line, have in their formation the keratin of less resistance, in contrast to what occurs in the sole wall of the hull[24].

The innermost layer is formed by epidermal layers that adhere to the dermal layers, forming the laminar corium. In the innermost portion, the dense and collagenous connective tissue is located, with great vascularization and innervation, called the coronary corium (dermis)[25], covering the distal phalanx and intimately connected with the epidermal laminae[23].

The outer structure of the hull is convex from medial to lateral and tilts obliquely from edge to edge. Dorsally, the angle of inclination of the wall concerning the ground is approximately 50º for the thoracic limb and 55º for the pelvic limb, on the lateral face, the angle gradually increases when reaching 100º in the heel. The curve of the wall is wider on the lateral side compared to the contralateral (medial) side, and the slope of the medial room is deeper than that of the lateral room. On the hull wall, there are ridges on the smooth surface, parallel to the coronary edge, which indicate variations in the growth of the hull tissue. The marking of thin parallel grooves is also found, extending from edge to edge, in an almost linear shape, and indicate the direction of the horny tubes [23,24,25].

The inner portion of the hull is concave across and holds about 600 thin primary epidermal lamellae, which extend from the coronary groove to the basal border of the wall. Each lamella supports approximately 100 secondary lamellae, arranged in cross-section, joining the hull and the corium. The five secondary lamellae are continuous on the internal face of the bars and fit with the corresponding lamellae of the lamellar corium[23].

The hull wall has the edges called coronary and basal. The coronary border has its thin proximal portion. Its outer surface is covered by a soft, light-coloured corneal layer called peroploid. The perimeter is a thin layer that lines the wall at a variable distance, distally, from the coronary band[24].

The basal rim of the hull is what should come into contact with the ground. Its thickness is greater at the front and decreases considerably from back to side, but there is a slight increase in beads. Its internal face is joined to the side of the sole by the white line[24].

Only the secondary epidermal blades and lamellar ochorium receive sensitive nerve endings, that is, they are sensitive regions of the hull. Also, there are still sympathetic motor nerve endings responsible for innervating the blood vessels present in the dermis[25].

The sole is most of the plantar surface of the hoof. It must be concave since its function is not to support the weight. Most of the palmar surface of the third phalanx is attached to it. It covers the entire palmar or plantar surface of the limb between the forceps and the groove, contemplating the bars. Where the outer edge of the sole meets the inner edge of the wall, a narrow white mark appears, called a 'white line', important for shoeing[25], as it serves as a reference for the farrier. The sole contains approximately 33% more water than the hull wall and is, therefore, less dense and resistant than the wall. It consists of two edges, a concave and a convex. The convex edge is joined to the wall through the white line. A ridge is in the middle corresponding to the groove's lateral grooves, on the concave edge of the sole[23].

The ranilha has a soft and thick elastic characteristic, with the apex cranially turned and the base located between the beads, it is in the middle of the hull bars, which contains approximately 45% humidity. It is produced by the papillae of another more internal groove, the sensitive groove. The latter is separated from the third phalanx, the navicular bone, and the insertion of the deep digital flexor tendon by the digital pad. The ranilha has the function of shock absorber in the hooves and assists in the blood irrigation for hooves[25]. On each side of the groove, there is a deep groove, called a collateral groove, which separates each side of the groove from its respective bar.

And there is a groove located in the middle of the plantar face of the base of the ranch, called the sagittal groove[23] corium. They are: perioplic chorion, coronary chorion, laminar chorion, sole chorion and groin chorion, respectively The sole surface of the thoracic limb is larger than that of the pelvic limb, this difference is responsible for the difference in surfaces between the distal phalanges pelvic and thoracic limbs[23;25].

The corium adheres to the periosteum above the convex surface of the 3rd phalanx. The weight or strength, applied to the 3rd phalanx, is transmitted to the hoof wall, which means that the horse's weight is supported by the hoof wall by the combination of sensitive and insensitive blades. This formation also allows the hull to grow only distally (not towards the joint) because the insensitive blades grow with the wall and the sensitive ones remain attached to the periosteum of the 3rd phalanx[24;25].

The hull and hull have four bones in their formation: proximal, middle and distal phalanges and the distal sesamoid bone or navicular bone.

The proximal phalanx, also called the first phalanx, is a long bone, located between the third metacarpal or metatarsal and the middle phalanx[25]. It is oriented obliquely (about 50-55º) distally and dorsally with the horizontal plane. The middle phalanx of the second phalanx is a short, flat dorsopalmar bone, located between the distal and proximal phalanx. Its direction corresponds to that of the first phalanx and its width is greater than its height. The distal navicular or sesamoid bone is palmar at the junction of the middle and distal phalanges and is in contact with both. It has the shape of a boat and its longitudinal axis is transverse to the member[24;25].

Inside the hull and almost surrounded by it, there is the distal phalanx or third phalanx. It consists of a spongy bone, which has channels, through which blood vessels pass. Like the scapula, and unlike the long bones of the limb, this phalanx articulates with another bone at just one end. This bone has no cortex or medullary cavity and is curved, following the shape of the hoof[23; 24;25]. Attached to the distal phalanx are collateral cartilages, in the form of irregular rhomboid plaques. They are curved in both planes: transverse and frontal, with the convex abaxial surface and the concave axial surface. Approximately half of the distal margin of the cartilages are linked to the palmar or plantar process of the distal phalanx and what remains extends palmarly. Also, approximately 50% of the cartilage is within the hull capsule, and the other part extends proximal to the hull capsule[24;25].

Anatomical References Planes and Axes

To facilitate the description of anatomical structures, imaginary lines were created that divide the animal's body from the anatomical position, quadrupedal position, with a look directed to the horizon. In this position the body of the horse can be delimited by planes tangent to its surface, which will form, due to the intersections of these planes, a parallelepiped[26; 27].

The plane that divides the animals' bodies into two hemi bodies is called the plane median, that which is closest to the median plane is called medial and an object or more distant surface is called lateral. The sagittal plane extends parallel to the median plane and corresponds to the right and left sides. The axes of movement join the center of opposite planes, in the case of the sagittal plane they join the left side with the right side, it is called the longitudinal axis, and in it, the flexion and extension movements are performed; the axes of movement are always perpendicular to the planes[26; 28; 27].

The transverse or segmental planes extend perpendicular to the plane median, whichever is closer to the head is called cranial and whichever is closer close to the tail, in caudal. The axis that leaves the transverse plane perpendicularly in the sagittal. The frontal or horizontal plane is perpendicular to the entire median plane and the one closest to the ventral floor adduction and abduction movements, as shown in figure 4.

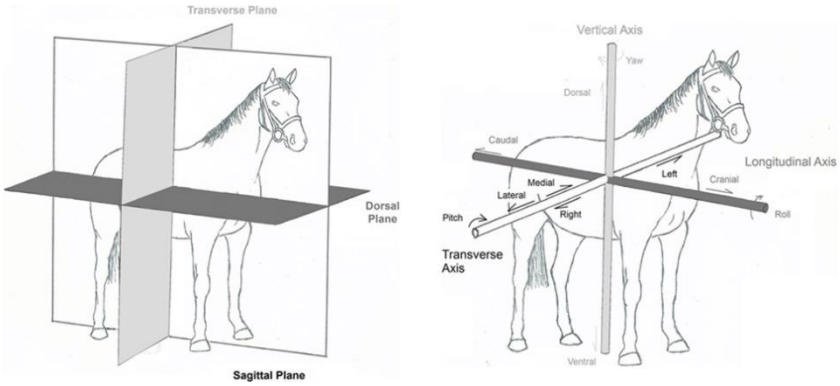

Figure 4: Anatomical planes in the equine, anatomical position. Adapted from Clayton, H. & Hobbs, S. (2017) Medial View, sagittal plane, transversal plane, and horizontal plane

Movement in the vertical or sagittal plane, the supporting pelvic limb supports the weight of the animal that will be pushed forward, and the other pelvic member is at the beginning of the body's progression phase. At this point, the vertex of the angle formed between the two limbs and the croup is at its lowest point. In sequence, the limb in progression causes the croup to rise, until the limb meets the ground and positions it at its lowest point again. This elevation is about 5 cm and occurs during the movement of the hind limbs, to simulate a wheel with its axis in the center of the animal's hip. The greater the lowering of the croup during the support phase, the greater the radius of the wheel, which accentuates movement in the vertical plane. During the step, there is a succession of support between the four members. Thus, in the pelvic limbs, two peaks of elevation and lowering of the croup are observed. The point of highest elevation occurs with a diagonal base because one of the pelvic members is in balance and the one with the least support with the lateral base when the two pelvic members are in contact with the ground[29].

The movement in the lateral horizontal plane occurs through the lateral deviations of the entire spine during limb displacement and occurs perpendicular to the longitudinal and transverse axis. The amount of these lateral deviations determines the animal's flexibility, so that the more flexible, the softer its gait, and the smaller the flexibility, the less smooth its gait[29].

In the lateral transverse plane, when the horse progresses, one of the pelvic members makes the hip is directed forward, while the other limb remains in support and the hip is directed backwards. There is a line that joins the two hips in the frontal plane and another perpendicular that is deviated to the side, in which the hip was directed backwards, to maintain the progression. In this same line, the horse directs its neck to the side that the hip advances and the inflexion of the spine form an arc around the rump to move the horse's belly to the opposite side when there is lateral support. In turn, the column is aligned when the support is diagonal. During each step, this occurs twice, once for the right side and once for the left side[29].

In the longitudinal plane on the long axis, when advancing the posterior limb, the center of mass is shifted to the contralateral side, and the body protrudes forward. To rebalance, his neck is elongated, and his head is lowered, in addition to advancing the contralateral forelimb to accommodate the center of mass. With the ground contact of the thoracic limb, the progressive movement is stopped and by inertia, as the tendency is to continue the progression, an imbalance occurs. To restore balance, the horse raises its head, minimizing the effects of inertia and facilitating the advancement of the contralateral pelvic limb. On this same side, the hip advances, and lowers, moving the center of mass back and rebalancing the system. In sequence, the contralateral thoracic limb moves forward, the center of mass moves forward and, when touching the ground, there is a new braking and a new imbalance and, with advancing the ipsilateral pelvic limb, balance is resumed with caudal displacement[29].

During each step, the horse performs four movements in the vertical plane, four in the horizontal plane, according to the transversal axis, and four according to the longitudinal axis, a total of 12 movements. Every minute the horse performs about 60 steps which correspond to 720 movements. The average duration of a riding session is thirty minutes and the horse produce approximately 21,600 movements[29].

Joints degrees of freedom and range of motion

A rigid body in three-dimensional space has six degrees of freedom of movement, which means that six independent coordinates are needed to describe its position and orientation in this space[30]. The six coordinates required to determine the position and orientation of the body can be, among others, the three coordinates of the position vector of the center of mass of the body and the three angles of rotation of a coordinate system fixed to the body under study, with a certain coordinate system, for example, attached to the laboratory. It is also known that when determining the spatial coordinates of three non-collinear points fixed to the rigid body, we obtain nine coordinates and three links (distances between points) sufficient to position it and orient it in space.

In order to understand the movements that the horse makes when making movements, it is first necessary to understand the types of mobile joints in its body, the planes and axes in which they move and their degrees of freedom.

In studies of three-dimensional movement, any rigid body has six degrees of freedom, which means that it needs six independent coordinates to describe its position and orientation in space[30]. These six degrees of freedom are the three Cartesian coordinates and the three angles of rotation, which were referred, in this case, to the Euler angles. To identify these Cartesian coordinates, the three-dimensional position of at least three non-collinear points in each segment is required.

How joints can be described in terms of degrees of freedom, that is, the number of planes and axes they can move. A monoaxial joint has an axis and a plane, and therefore has a degree of freedom[21,27], as shown in Figure 5, the metacarpophalangeal joint as an example of this type of joint.

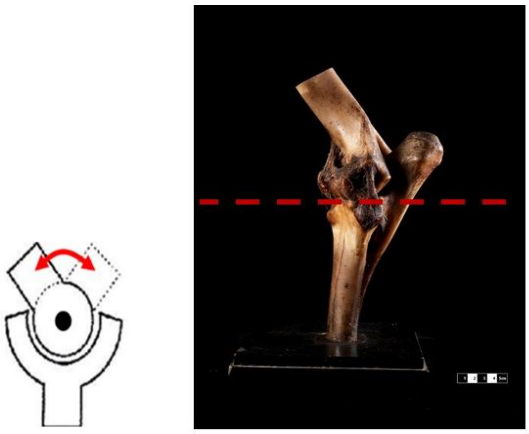

Figure 5: Metacarpophalangeal joint with 1 degree of freedom. Adapted from Museum of Veterinary Anatomy of the Faculty of Veterinary Medicine and Animal Science at USP (2020)

The biaxial articulation has two axes and two planes of movement, resulting in two degrees of freedom. Finally, the last type of joint is the triaxial joint, where it presents three axes of movement and 3 three planes, resulting in three degrees of freedom[21;27], as shown in Figure 6, the hip joint.

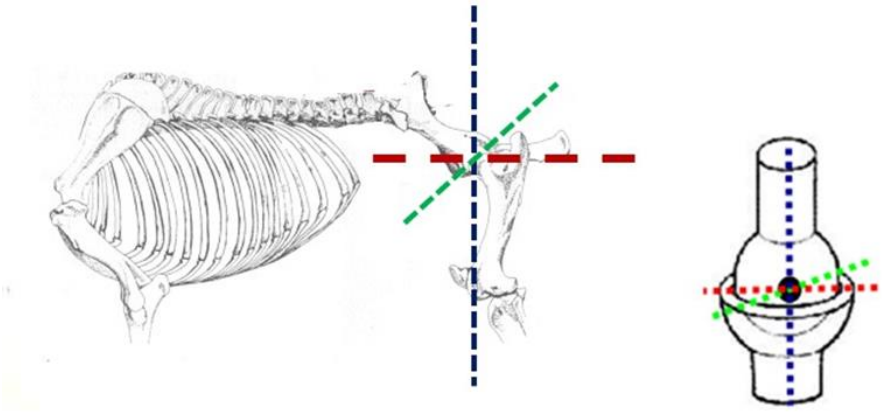

Figure 6: Hip joint with 3 degrees of freedom. Adapted from Museum of Veterinary Anatomy of the Faculty of Veterinary Medicine and Animal Science at USP (2020)

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