A THREE-DIMENSIONAL EQUINE MODEL

3D Horse Model: Full Body Model, Anatomical and markers structure

July, 2020

TECHNICAL REPORT

PTDC/CVT-CVT/32613/2017

EquiPerfoRM

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

supported by:

A THREE-DIMENSIONAL EQUINE MODEL

3D Horse Model: Full Body Model

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CONTENTS

REPORT OBJECTIVE

In 2D studies of horse walking, angular variables are generally treated as flexion and extension in the sagittal plane[1;2;3]. Since the joints of the horse's limbs evolved to move primarily under the sagittal plane[4], most studies and kinematic variables can be captured laterally to the horse, under a 2D plane.

However, for studies carried out in the field of sport or in diagnosis and rehabilitation, it is important to study adduction / abduction or internal / external rotations, which is only possible with 3D analysis[5;6;7], thus being the proposed model in this study it will be a 3D analysis model. Thus, this technical report aims to characterize the 3D model of horse segments.

Technical report aims to characterize the 3D model of horse´s anatomical segments and the localization of the Vicon markers in each one of those segments. This multi markers set will be the basic spatial framework of reference to reconstruct the 3D model.

This technical report will explain:

1. Outputs from full body model horse.
2. Horse´s skeleton and marker set for 3D Full Body Modeling.
3. Definition of anatomical segments and the markers placement.
4. Horse´s markers placement

I – OUTPUTS FROM FULL BODY MODEL HORSE

Use the model for the forelimb and hind limb of the horse's body if a specific assessment of these limbs is required through kinematic calculations. If the evaluation is full body, use the complete model for the kinematic calculations. The segments used by this model are both for the right side (R) and the left side (L).

II – HORSE´S SKELETON AND MARKER SETS FOR 3D FULL BODY MODELING

The markers used are spherical with 12mm in diameter fixed to the horses' skin with double-sided tape and adhesive tape, so that their circular shape is maintained when viewed from different angles[2].

These markers must be placed over predetermined anatomical regions[8;9] and can be attached to the skin[10; 11] or directly attached to the bone[12;13]. To study the location of the markers, EquiPerfoRM used a horse skeleton from the Faculty of Veterinary Medicine of Universidade Lusófona. This skeleton was moved to Movlab to assist the team in making the decision about the location of these retro-reflective marks, this location was based on studies already carried out on horses published in specialized scientific journals and documents from the previous project (PTDC / CVT / 113480/2009), as shown in figure 1.

Figure 1: Representation of the set of full body markers on the horse's skeleton. The markers selected in the highlighted landmarks on the left side of the horse represent the same scheme on the right side. *Source: EquiPERFORM project data January 2020*

After defining the position of each marker on the skeleton, they were glued to the bone horse. When these are placed on the skin to represent the movement of the skeleton, it is impossible to avoid the movement of the skin and subcutaneous tissue on the skeleton during horse walking[2], errors can be introduced [2,8,9,10,13].

II – DEFINITION OF ANATOMICAL SEGMENTS AND POSITION OF RETROREFLECTIVE MARKERS

The models of anatomical segments available have a variable complexity depending on the total number of segments and the anatomical structures (skeletal, muscular and articular system) considered, and can be classified into one of the following categories: Full body, Upperbody, Lowerbody, SingleJoint[1;2.] In the kinematic analysis, the segments of the model are represented by rigid bodies. Depending on the movement analyzed, each segment may be represented by several rigid bodies, resulting in multi-segment models. This modeling allows to represent more accurately the mechanical behavior of the studied structures. Another source of variability comes from the use of protocols with a different number and location of markers, in the representation of a given model.

In the present model proposed, it will be defined as full body, represented by 98 retroreflective markers, allowing to define 26 different segments (head, neck, trunk, scapula, humerus, radius and ulna, metacarpus, fore fetlock and pastern (fore P1), fore hoof, hip/coxal, femur, tibia and fibula, metatarsus, hind fetlock and pastern (hind P1), hind hoof).

The origin of each local reference frame for each segment defined by the three-dimensional kinematic model is an intersection of three axes (X, Y and Z), registered according to the following items below:

Z - axis: vector longitudinal to the segment. In cases where segment is composed by 4 or more retroreflective markers (described in figures 2,3,4,5 and 6), the orientation of the longitudinal axis is defined as the vector that passes by the mid-point determined

[1] Manual Vicon Nexus 2.9 (https://docs.vicon.com/display/Nexus210/Vicon+Nexus+User+Guide)

by both proximal markers and by the mid-point defined by both distal markers, instead, if segment is composed by 3 retroreflective markers, z-axis is defined as the vector with the orientation of the vector that crosses the lateral markers of the segment and which passes by the mid-point determined by the distal markers of the segment;

X - axis: vector pointing in a caudalcranial direction. In cases where segment is composed by 4 or more retroreflective markers (described in figures 2,3,4,5 and 6), the orientation of caudalcranial vector is defined as the vectorial product between the longitudinal axis and the vector that goes through the mid-point determined by the lateral markers and by the mid-point determined by the medial markers in a four marker segment, instead, if segment is composed by 3 retroreflective markers, x-axis is defined as the vector with the orientation of the vectorial product between the longitudinal axis and the vector that passes through mid-point determined by the distal markers of the segment;

***Y* – axis:** Vector pointing in a lateralmedial direction. Regardless segment is composed by 3 or more segments, this vector has the orientation of the vector defined by the vectorial product between the latter axes (Z and X axis).

Head, Neck and Trunk

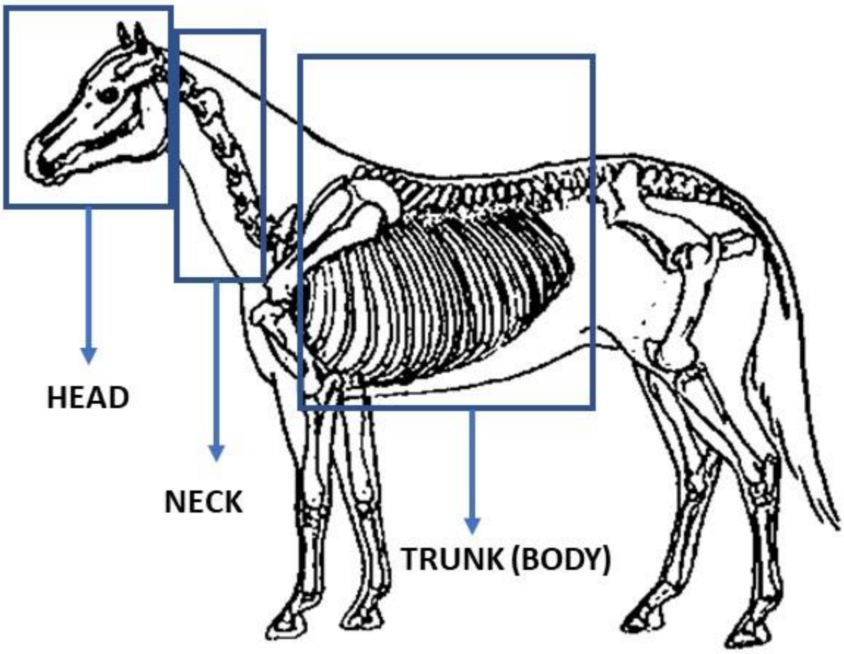
The head of the horse is composed of 16 bones and these are classified according to their location, being the bones of the neurocranium (brain box): Occipital, Sphenoid, Ethmoid, Interparietal, Parietal, Frontal and Temporal; and viscerocranial bones (face): Maxillary, Nasal, Lacrimal, Zygomatic, Incisor, Vomer, Palatine, Pterygoids and Mandible.

The spine starts from the skull and goes to the tip of the tail. It consists of bones called vertebrae. The sequence from the skull is as follows: Atlas, Axis, cervical vertebrae, thoracic vertebrae, lumbar vertebrae, sacral vertebrae and caudal or coccygeal vertebrae. The functions of the spine are the protection of the spinal cord, movements of flexion, extension, and rotation, in addition to supporting the body and various organs such as stomach and intestines.

The ribs are elongated and curved, its body is more rounded than flat. The extremities are articulated to the thoracic vertebrae and the sternum. They have the function of protecting organs such as heart and lungs and assist in the breathing process, together with the diaphragm.

The sternum is formed by three parts: manubrium cartilage, sternum body (sternum) and xiphoid cartilage. They assist in the protection and support of organs. It articulates laterally with the ribs on the right and left side, forming the rib cage.

Figure 2 show the anatomical marks of the head, neck and trunk axes and their retro-reflective markers proposed in the construction of the three-dimensional biomechanical model presented in this technical note. The markers on the right and left side are fixed in a similar way (with some symmetry).



ANATOMICAL SEGMENT	MAKER NUMBER	MARKER NAME	MARKER ANATOMIAL REFERENCE
HEAD	1	NC	Nucal Crest
	2	FCL	Left Facial Crest (cranial)
	3	FCR	Right Facial Crest (cranial)

ANATOMICAL SEGMENT	MAKER NUMBER	MARKER NAME	MARKER ANATOMIAL REFERENCE
NECK	4	C1L	Left Cranial portion of the atlas wing
	5	C1R	Right Cranial portion of the atlas wing
	6	C5L	Left Transverse Process of the C5
	7	C5R	Right Transverse Process of the C5

ANATOMICAL SEGMENT	MAKER NUMBER	MARKER NAME	MARKER ANATOMIAL REFERENCE
TRUNK (BODY)	8	T4	Spinous Process of the T4
	9	T18	Spinous Process of the T18
	10	L6	Spinous Process of the L6
	11	S1	Spinous Process of the S1
	12	MC	Manubrial Cartilage

Figure 2: Head, Neck and Trunk marker set in the Equine Three-dimensional Biomechanics Model. Source: *EquiPERFORM project data , 2020*.

Table 1 shows the orientation of the three-dimensional spatial of the head, neck and trunk segments proposed in the present model.

Table 1: Orientation of the three-dimensional spatial of the segments head, neck, and trunk

SEGMENT	ORIGIN	ORIENTATION AXIS X	ORIENTATION AXIS Y	ORIENTATION AXIS Z
HEAD	MidPoint (LFC, RFC, NC)	LFC → RFC	Perpendicular to Z and X	VP Rostral (MidPoint LFC, RFC, NC)
NECK	MidPoint (Vp Caudal, Vp Cranial, Vp Left, Vp Right)	Perpendicular to Z and Vector Vp Left → Vp Right	Perpendicular to Z and X	Vp Caudal → Vp Cranial
TRUNK	MidPoint (T4, T18, L6, S1, MC)	Perpendicular Z and Vp Left → MC	Perpendicular to Z and X	S1 → T4

Legend: Vp point: calculated as the midpoint of two anatomical markers (points).

Forelimb

The forelimb is formed by the bones: scapula, humeros, radius and ulna (forearm), pasterns, fore fetlock and pastern (fore p1), fore hoof.

The Scapula Bone is shaped like a tennis racket, being mostly a flat bone. It is linked to walking, being responsible for stretching the thoracic limbs (bringing the arm back and forth in the walking process). That is why the angle of the Scapula is important for the morphological evaluation of horses, since, from it, we can know if the animal's step is long or not, being important for running animals (the more horizontal the angle, the better, because the longer is the animal's step, the greater the stretch of the arm).

It is positioned on the ribs connected by muscles and tendons and is articulated to the humerus. The equine humerus has the intermediate tubercle as a feature, in the lateral direction. It is a long bone; it is articulated to the O. Scapula and to the bones Radio and Ulna.

The bones of Radio and Ulna are fused together, and Ulna extends throughout the entire body of the Radio (unlike ruminants where Ulna ends up in the middle of the Radio's body). They are long bones and articulate with the Humerus and the Carpus. They perform the movement of raising and lowering the arm.

Carpus bones are irregular and small. They are arranged in accessory carpal (lateral face), ulnar carpal (lateral face), intermediate carpal, O. radial carpal (medial face), carpal II and carpal III (which are fused) and carpal IV (lateral). These bones form the knee region in horses. They are linked to Radio and Ulna, and Metacarpus.

The bones of the metacarpal are long. Arranged in metacarpal IV, metacarpal III (the longest of all metacarpal bones, it is between the other two) and metacarpal II. Bones IV and II are fused in III, and their length extends to the middle of the body of the metacarpal III. They are articulated with the carpal bones, the sesamoid, and the proximal phalanx.

Sesamoids are irregular and square. The proximal sesamoid has a protective function of the metacarpals when walking, if the impact is large and they touch the floor. And the distal sesamoid has a protective function of the hull in the impact of walking.

The articulation between the metacarpal bones, proximal sesamoids and proximal phalanx form the anatomical region called the boletus. A region that suffers a lot from the exaggeration of physical activity, getting the ligaments compromised, causing swelling and a lot of pain to the animals.

The phalanges are divided into proximal, middle, and distal (surrounded by the hull). The proximal is articulated to the metacarpal and sesamoid, and the distal phalanx is articulated to the distal sesamoid. The phalanges that remained in the equine species were only the III (third finger, the other phalanges have evolved over the course of evolution). They are considered long bones.

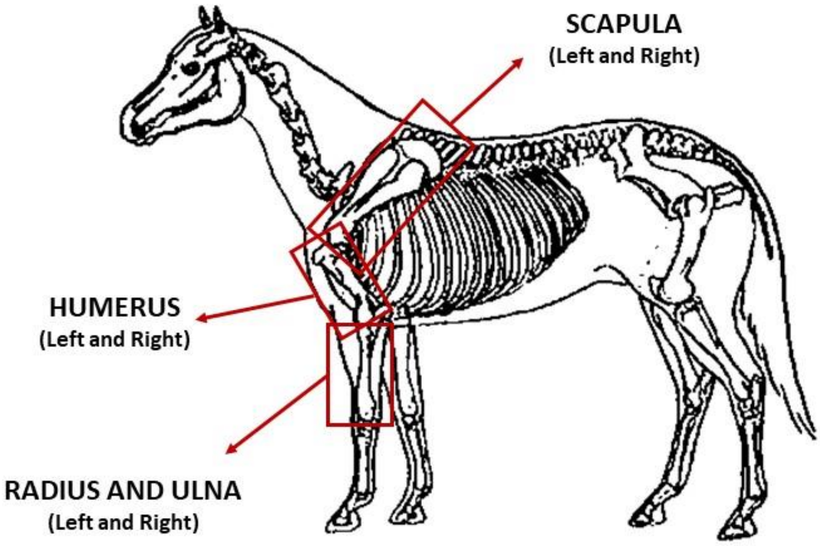
Due to their proximity to the center of gravity, the forelimbs mainly have a supporting role, supporting about 58% of the weight[2; 14;15].

Horses do not have a collarbone, the forelimb being connected to the trunk only through muscles (sinsarcosis), which allows greater scapular mobility and, consequently, an increase in stride length. These muscles are called extrinsic, with insertions in the limb and trunk[16]. Intrinsic muscles are the muscles of the limb itself. The intrinsic ones are smaller in volume, when compared to the extrinsic musculature, with short and strained muscle fibers as well as long tendons[17].

The thoracic limb of horses shows concentrated muscle groups proximally, which extend over long tendons as they move towards distal, allowing the creation of a passive system of “springs” and thus reducing the cost of locomotion[17;18;19].

The tendons of vertebrate animals have a uniform constitution and low energy dissipation. When tension is exerted on these tendons, they return about 93% of elastic energy, with only 7% being dissipated in the form of heat[20,17].

Figures 3 and 4 show the anatomical marks of the segments scapula, humerus, radius and ulna (Forearm), pasterns, fore fetlock and pastern (Fore P1) and fore hoof and their respective retro-reflective markers (42 marks) proposed in the construction of the biomechanical model three-dimensional model proposed in this technical note. The markers were placed on the forelegs on the left right side of the horse.

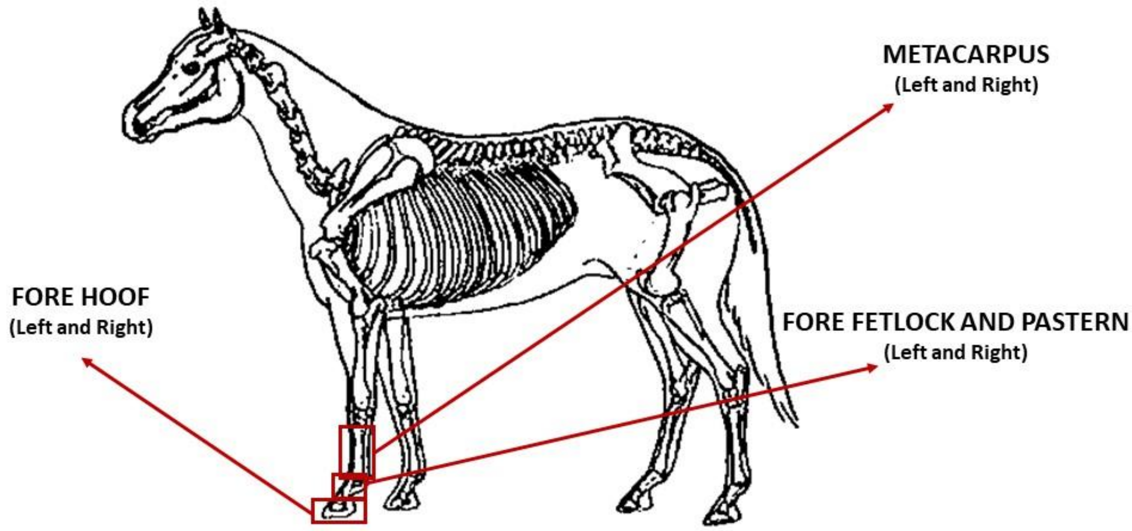


ANATOMICAL SEGMENT	MAKER NUMBER	MARKER NAME	MARKER ANATOMIAL REFERENCE
SCAPULA – LEFT	13	LPSC	Left Caudal Dorsal Border of the Scapula
	14	LMdSC	Left Tuberosity of the scapula spine (on the flattest area)
	15	LDSC	Left Cranial Part of the greater tubercle of the humerus
SCAPULA - RIGHT	16	RPSC	Right Caudal Dorsal Border of the Scapula
	17	RMdSC	Right Tuberosity of the scapula spine (on the flattest area)
	18	RDSC	Right Cranial Part of the greater tubercle of the Humerus

ANATOMICAL SEGMENT	MAKER NUMBER	MARKER NAME	MARKER ANATOMIAL REFERENCE
HUMERUS – LEFT	19	LDSC	Left Cranial Part of the greater tubercle of the humerus
	20	LMdHUM	Left Deltoid Tuberosity of the humerus
	21	LDHUM	Left Lateral Epicondyle of the humerus
HUMERUS – RIGHT	22	RDSC	Right Cranial Part of the greater tubercle of the Humerus
	23	RMdHUM	Right Deltoid Tuberosity of the Humerus
	24	RDHUM	Right Lateral Epicondyle of the Humerus

ANATOMICAL SEGMENT	MAKER NUMBER	MARKER NAME	MARKER ANATOMIAL REFERENCE
RADIUS AND ULNA – LEFT (FOREARM)	25	LPULNA	Left Lateral Coronoid Process of the Ulna
	26	LLULNA	Left Lateral Styloid Process
	27	LMULNA	Left Medial Styloid Process
	28	LACC	Palmar Border of the Left Accessory carpal bone
RADIUS AND ULNA – RIGHT (FOREARM)	29	RPULNA	Right Lateral Coronoid Process of the Ulna
	30	RLULNA	Right Lateral Styloid Process
	31	RMULNA	Right Medial Styloid Process
	32	RACC	Palmar Border of the Right Accessory carpal bone

Figure 3: Forelimb: Scapula, Humerus and Radius and Ulna marker set, with the representation of the different segments, the predetermined landmarks in each segment and the abbreviated marker name. Source: *EquiPERFORM project data , 2020*.



ANATOMICAL SEGMENT	MAKER NUMBER	MARKER NAME	MARKER ANATOMIAL REFERENCE
METACARPUS – LEFT	33	LLPMTC	Left Proximal Extremity of the interosseous space between IV and III metacarpus
	34	LMPMTC	Left Proximal Extremity of the interosseous space between II and III metacarpus
	35	LLDMTC	Left Distal Extremity of the IV metacarpus
	36	LMDMTC	Left Distal Extremity of the II metacarpus
	37	LFSES	Left – Palmar to the intersesamoidean space
METACARPUS – RIGHT	38	RLPMTC	Right Proximal Extremity of the interosseous space between IV and III metacarpus
	39	RMPMTC	Right Proximal Extremity of the interosseous space between II and III metacarpus
	40	RLDMTC	Right Distal Extremity of the IV metacarpus
	41	RMDMTC	Right Distal Extremity of the II metacarpus
	42	RFSES	Right – Palmar to the intersesamoidean space

ANATOMICAL SEGMENT	MAKER NUMBER	MARKER NAME	MARKER ANATOMIAL REFERENCE
FORE FETLOCK AND PASTERN – LEFT (FOREP1)	43	LLFP1	Left – Lateral proximal tuberosity of P1
	44	LMFP1	Left – Medial proximal tuberosity of P1
	45	LLFP2	Left – Lateral proximal tuberosity of P2
FORE FETLOCK AND PASTERN – RIGHT (FOREP1)	46	RLFP1	Right – Lateral proximal tuberosity of P1
	47	RMFP1	Right – Medial proximal tuberosity of P1
	48	RLFP2	Right – Lateral proximal tuberosity of P2

ANATOMICAL SEGMENT	MAKER NUMBER	MARKER NAME	MARKER ANATOMIAL REFERENCE
FORE HOOF – LEFT (LFOREP3)	49	LFFP3	Left – 1cm below the coronary band (extensor process of P3)
	50	LLFP3	Left – Quarter at the level of lateral palmar process of P3
	51	LMFP3	Left – Quarter at the level of medial palmar process of P3
FORE HOOF – RIGHT (LFOREP3)	52	RLFP1	Right – Lateral proximal tuberosity of P1
	53	RMFP1	Right – Medial proximal tuberosity of P1
	54	RLFP2	Right – Lateral proximal tuberosity of P2

Figure 4: Forelimb: Metacarpus, Fore Fetlock and Pastern (Fore P1) and Fore Hoof marker set, with the representation of the different segments, the predetermined landmarks in each segment and the abbreviated marker name. Source: *EquiPERFORM project data , 2020*.

Table 2 shows the orientation of the three-dimensional spatial of forelimb segments proposed in the present model.

Table 2: Orientation of the three-dimensional spatial of the forelimb segments

SEGMENT	ORIGIN	ORIENTATION AXIS X	ORIENTATION AXIS Y	ORIENTATION AXIS Z
SCAPULA (L/R)	Mid-distance between *Humerus* and *Scap*	Perpendicular to Z and a vector passes through *MidScap* and a point between *Humerus* → *Scap*	Perpendicular to X and Z	*Humerus* → *Scap*
HUMERUS (L/R)	Mid-Distance between *ProxRadius* and *Humerus*	Perpendicular to Z and a vector passes through MdHU and a point between *ProxRadius* → *Humerus*	Perpendicular to X and Z	Mid-distance between *ProxRadius* and *Humerus*
RADIUS AND ULNA (L/R)	MidPoint (Pulna,*Lulna, Mulna, Acc*)	Perpendicular to Z and vector *LUlna* → *Acc*	Perpendicular to Z and X	*Vp distal* → *Vp proximal*
METACARPUS (L/R)	MidPoint (LPMTC, MPMTC, LDMTC, MDMTC, FSES)	Perpendicular to Z and vector *Vp lateral* → *Vp medial*	Perpendicular to Z and X	*Vp distal* → *Vp proximal*
FORE FETLOCK AND PASTERN (L/R) – P1+P2	MidPoint (LFP1, LFP2, MFP1)	Perpendicular to Z and vector Vp lateral → Vp Medial	Perpendicular to Z and X	*LFP2* → *LFP1*
FORE HOOF (L/R)	MidPoint (MFP3, FFP3, LFP3)	Perpendicular to Z and vector Vp lateral → Vp medial	Perpendicular to Z and X	*LFP3* → *FFP3*

Legend: Vp point: calculated as the midpoint of two anatomical markers (points).

Hindlimb

The hindlimb are formed by bones: Hp / Coxal, Femur, Tibia and Fibula, Metatarsus, Hind Fetlock and Pastern (hind P1), Hind Hoof.

The Coxal Bone is formed by the fusion of three bone pairs: two Ilios, two Ischia and two Pubis, all are considered flat bones. Ilios presents the auricular surface where the sacrum is articulated. Between the Ischia and Ilios is the acetabulum, where the femur is articulated.

The equine femur has as its particularity the third trochanter, in the lateral direction. It is a long bone, it is articulated to the Coxal, Patella and Tibia. Performs the front and back movement of the animal's limb.

The patella is a sesamoid bone of irregular shape and has the function of protecting the ligaments of the femur joint.

The Tibia and Fibula bones are fused together, the Fibula is needle-shaped and extends to the middle of Tibia's body. The tibia is a long bone and joins the fibula, femur, and tarsal bones. They perform the up and down movement of the leg.

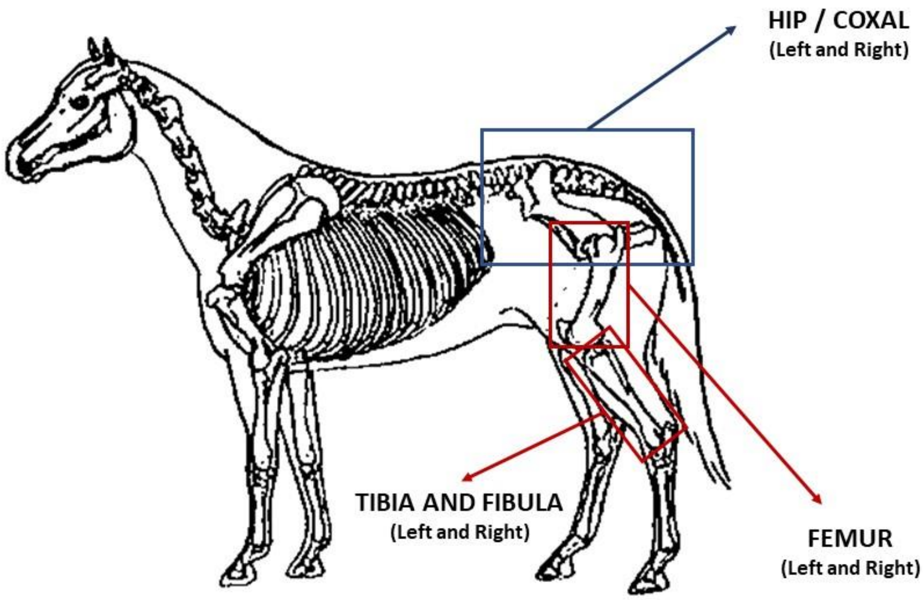
The Tarsus is composed of the Talus, Calcaneus, Central, 1st and 2nd Tarsian bones (which are fused), 3rd Tarsian and 4th Tarsian. Together they form the anatomical region called the Hock. They participate in the leg up and down movement. All have an irregular shape, with the calcaneus bone being the largest among them, the talus is the second largest and has a cuboid shape just like the others. The 1st and 2nd Tarsians are fused.

The horses have the 2nd Metatarsal, 3rd Metatarsal and 4th Metatarsal bones. The biggest of all is the 3rd, with the 2nd and 4th stretching only halfway up the body. They are called long, irregular bones. They are articulated to the tarsal bones, sesamoid and proximal phalanx.

The hind limb of the horse is responsible for supporting 42% of the body mass[14]. The shape of this limb allows it to play a crucial role in longitudinal propulsion. Your muscles are responsible for providing the necessary work for acceleration and for raising the center of mass when moving uphil[l2,19].

Many of the muscles of the hind limbs are multiarticular and have several fascial connections, which makes it difficult to distinguish between intrinsic and extrinsic muscles[17]. Proximally, the pelvic limb is characterized by large muscular volumes and long fascicles, while more distally, the muscular component presents small and strained volumes and fascicles. In general, the proximal musculature is more specialized in generating work, while the distal musculature is generating economic strength[19].

Figures 5 and 6 show the anatomical marks of the segments hip / coxal, femur, tibia and fibula, metatarsal, hind fetlock and pastern (hind p1), hind hoof and their respective retro-reflective markers (44 marks) proposed in the construction of the three-dimensional biomechanical model proposed in this technical note. The markers were placed on the forelegs on the left right side of the horse.

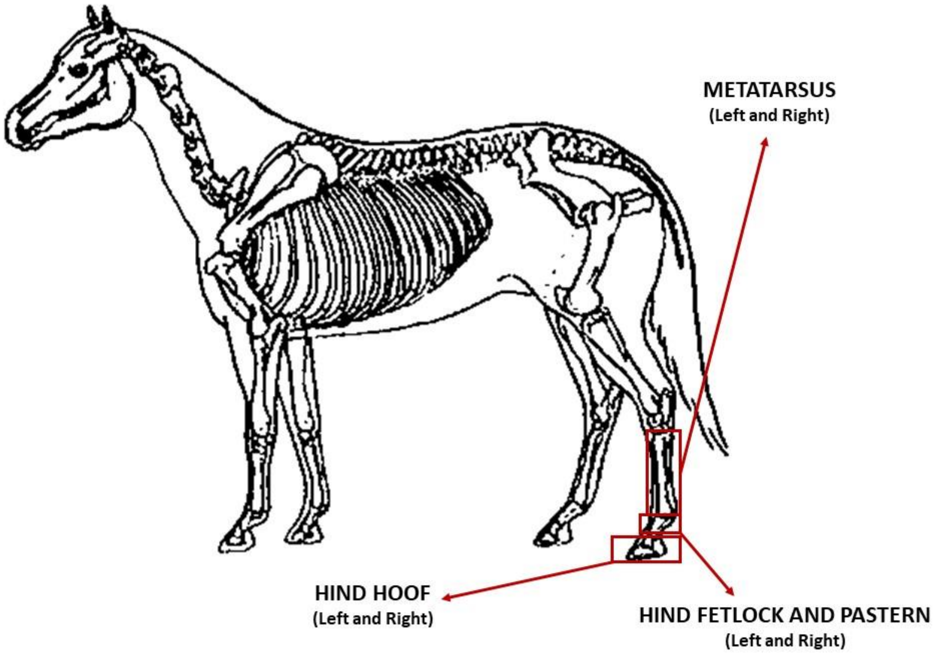


ANATOMICAL SEGMENT	MAKER NUMBER	MARKER NAME	MARKER ANATOMIAL REFERENCE
HIP – LEFT(COXAL)	55	LCoxal	Left – Caudoventral Extremity of the coxal tuber
	56	LIschial	Left – Ischial tuber
HIP – RIGHT (COXAL)	57	RCoxal	Right – Caudoventral Extremity of the coxal tuber
	58	RIschial	Right – Ischial tuber

ANATOMICAL SEGMENT	MAKER NUMBER	MARKER NAME	MARKER ANATOMIAL REFERENCE
FEMUR – LEFT	59	LPFEM	Left - Greater trochanter of the femur
	60	LMdFEM	Left - Lateral Supracondylar Tuberosity of the Femur
	61	LDFEM	Left – Lateral Epicondyle of the Femur
FEMUR – RIGHT	62	RPFEM	Right - Greater trochanter of the femur
	63	RMdFEM	Right - Lateral Supracondylar Tuberosity of the Femur
	64	RDFEM	Right – Lateral Epicondyle of the Femur

ANATOMICAL SEGMENT	MAKER NUMBER	MARKER NAME	MARKER ANATOMIAL REFERENCE
TIBIA AND FIBULA – LEFT	65	LPTIB	Left Tibial Tuberosity
	66	LMdTIB	Left – Middle distance between marker 62 and 64
	67	LLTIB	Left – Proximal to the lateral malleolus of the Fibula
	68	LMTIB	Left – 2cm proximal to the medial malleolus of the Tibia
TIBIA AND FIBULA – RIGHT	69	RPTIB	Right Tibial Tuberosity
	70	RMdTIB	Right – Middle distance between marker 82 and 84
	71	RLTIB	Right – Proximal to the lateral malleolus of the Fibula
	72	RMTIB	Right – 2cm proximal to the medial malleolus of the Tibia

Figure 5: Hindlimb: Hip/Coxal, Femur and Tibia and Fibula marker set, with the representation of the different segments, the predetermined landmarks in each segment and the abbreviated marker name. Source: *EquiPERFORM project data , 2020*.



ANATOMICAL SEGMENT	MAKER NUMBER	MARKER NAME	MARKER ANATOMIAL REFERENCE
METATARSUS – LEFT	73	LLDMTT	Left – Base of the IV Metatarsus
	74	LLPMTT	Left Proximal Extremity of the interosseous space between IV and III metatarsus
	75	LMPMTT	Left - Proximal Extremity of the interosseous space between II and III metatarsus
	76	LLDMTT	Left – Distal Extremity of the IV Metatarsus
	77	LMDMTT	Left – Distal Extremity of the II Metatarsus
	78	LHSES	Left – Plantar to the intersesamoidean space
METATARSUS – RIGHT	79	RLDMTT	Right – Base of the IV Metatarsus
	80	RLPMTT	Right Proximal Extremity of the interosseous space between IV and III metatarsus
	81	RMPMTT	Right - Proximal Extremity of the interosseous space between II and III metatarsus
	82	RLDMTT	Right – Distal Extremity of the IV Metatarsus
	83	RMDMTT	Right – Distal Extremity of the II Metatarsus
	84	RHSES	Right – Plantar to the intersesamoidean space

ANATOMICAL SEGMENT	MAKER NUMBER	MARKER NAME	MARKER ANATOMIAL REFERENCE
HIND FETLOCK AND PASTERN - LEFT (HINDP1)	85	LLHP1	Left – Lateral proximal tuberosity of P1
	86	LMHP1	Left – Medial proximal tuberosity of P1
	87	LLHP2	Left – Lateral proximal tuberosity of P2
	88	LMHP2	Left – Medial proximal tuberosity of P2
HIND FETLOCK AND PASTERN - RIGHT (HINDP1)	89	RLHP1	Right– Lateral proximal tuberosity of P1
	90	RMHP1	Right – Medial proximal tuberosity of P1
	91	RLHP2	Right – Lateral proximal tuberosity of P2
	92	RMHP2	Right – Medial proximal tuberosity of P2

ANATOMICAL SEGMENT	MAKER NUMBER	MARKER NAME	MARKER ANATOMIAL REFERENCE
HIND HOOF – LEFT (LHINDP3)	93	LFHP3	Left – 1cm below the coronary band (extensor process of P3)
	94	LLHP3	Left – Quarter at the level of lateral palmar process of P3
	95	LMHP3	Left – Quarter at the level of medial palmar process of P3
HIND HOOF – RIGHT (LHINDP3)	96	RFHP3	Right – 1cm below the coronary band (extensor process of P3)
	97	RLHP3	Right – Quarter at the level of lateral palmar process of P3
	98	RMHP3	Right – Quarter at the level of medial palmar process of P3

Figure 6: Hindlimb: Metatarsus, Hind Fetlock and Pastern (Hind P1) and Hind Hoof marker set, with the representation of the different segments, the predetermined landmarks in each segment and the abbreviated marker name. Source: *EquiPERFORM project data , 2020*

Table 3 shows the orientation of the three-dimensional spatial of hindlimb segments proposed in the present model.

Table 3: Orientation of the three-dimensional spatial of the hindlimb segments

SEGMENT	ORIGIN	ORIENTATION AXIS X	ORIENTATION AXIS Y	ORIENTATION AXIS Z
HIP/COXAL (L+R)	Midpoint (*Vp distal, Vp proximal, Vp left, Vp right*)	Perpendicular to Z and vector *Vp left → Vp right*	Perpendicular to Z and X	*Vp distal → Vp proximal*
FEMUR (L/R)	Mid-Distance between DFEM and PFEM	Perpendicular to Z and vector passes trough MdFEM and a point between to DFEM → PFEM	Perpendicular to Z and X	*DFEM → PFEM*
TIBIA AND FIBULA (L/R)	MidPoint (Vp distal, Vp proximal, Vp left, Vp right)	Perpendicular to Z and Vector Vp lateral → Vp medial	Perpendicular to Z and X	*Vp distal → Vp proximal*
METATARSUS (R/L)	MidPoint (Vp distal, Vip proximal, LPMTT, MDHTT)	Perpendicular to Z and vector LPMTT → MDMTT	Perpendicular to Z and X	*Vp distal → Vp proximal*
HIND FETLOCK AND PASTERN (L/R) – P1+P2	Midpoint (*Vp distal, Vp proximal, Vp medial, Vp lateral*)	Perpendicular to Z and vector Vp lateral → Vp medial	Perpendicular to Z and X	*Vp Lateral → Vp Medial*
HIND HOOF (L/R)	MidPoint (MFP3, FFP3, LFP3)	Perpendicular to Z and vector Vp lateral → Vp medial	Perpendicular to Z and X	*LFP3 → FFP3*

Legend: Vp point: calculated as the midpoint of two anatomical markers (points).

IV – HORSE´S MARKERS PLACEMENT

After defining the position of each marker on the skeleton, the EquiPERFORM team traveled to Clínica Santo Estevão to carry out experimental tests with horses. Therefore, the retroreflective markers that make up the horse's whole-body model were fixed on the horse's body with the aid of a double-sided tape and an adhesive tape, as shown in figure 7. When these are placed on the skin to represent the movement of the skeleton, it is impossible to avoid the movement of the skin and subcutaneous tissue in the skeleton during the walk, errors can be introduced[2,8,9,10,13].

Figure 7: Representation of the set of full body markers on the horse's body. The markers selected in the highlighted markers on the left side of the horse represent the same scheme on the right side. *Source: EquiPERFORM project data, January, and February 2020*

If the position of each marker is known in relation to a specific position of the precise, the exact location of the placement of the markers must be precise to avoid possible 3D reconstruction errors of the horse[2].

The kinematic data of the positioning of the markers were collected in three days, one day each week, with the aim of validating the positioning of the anatomical marks that make up this proposed three-dimensional model.

To acquire the static data of the positioning of the markers, the horse was guided by a veterinarian from the clinic to stand still, this procedure was carefully repeated for each attempt. The acquisition of the kinematic data was performed with the Nexus 2.9 software[2], which allowed the acquisition of the three-dimensional global coordinates of the retroreflective markers.

[2] Manual Vicon Nexus 2.9 (https://docs.vicon.com/display/Nexus210/Vicon+Nexus+User+Guide

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