Horse's gait motion analysis system based on videometry

Sistema de análisis de movimiento para caballos basado en videometría

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Resumen

En este trabajo se describe el desarrollo y el uso de un nuevo sistema de análisis de movimiento para investigar y evaluar la cinemática 2D de la marcha equina, el cual utiliza un software de captura de movimiento, unos cálculos matemáticos y una interfaz gráfica diseñada para evaluar el modelo locomotor de los caballos. A partir de secuencias de vídeo de la marcha equina, registradas por cámaras de alta velocidad, se obtienen las coordenadas (x, y) a través de software TEMA 3.0; luego, se calculan variables cinemáticas, tales como longitud de los segmentos corporales, ángulos de las articulaciones, trayectorias de cada marcador y curvas de flexión-extensión de las articulaciones, y con la interfaz gráfica desarrollada en el software Mathematica se genera una simulación 2D del movimiento de los caballos. Esta herramienta tiene como objetivo ayudar a investigar y evaluar la marcha equina y analizarla de forma objetiva (cualitativa y cuantitativa), aunque se puede utilizar en diferentes campos de análisis de la marcha. Se elimina la subjetividad del diagnóstico realizado por los veterinarios y permite hacer diferentes análisis, evaluaciones, investigaciones y el seguimiento de la marcha equina.

Palabras clave: análisis de movimiento; ciclo de marcha; cinemática; movimiento equino; videometría.

Abstract

In this work, we describe the development and use of a new motion analysis system to investigate and evaluate 2D kinematic of the equine gait. This system uses a motion capture software, mathematical calculations, and a graphic interface designed to evaluate locomotor patterns of the horses. From video sequences of equine motion recorded by high-speed cameras, we obtained the coordinates (x, y) using TEMA 3.0 software; then, we calculated kinematic variables such as length of body segments, joint's angles,

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trajectories of each marker, and joint flexion-extension curves; and with a graphical interface developed in the Mathematica software, we generated a 2D simulation of the horses movement. This tool aims at helping to investigate and evaluate the equine gait, and analyze it in an objective way (qualitative and quantitative); However, it can be used in different fields of gait analysis. This tool removes the subjectivity of the diagnosis made by veterinarians, and allows to perform different analyses, evaluations, researches, and monitoring of the equine gait.

Keywords: equine motion; gait cycle; kinematic; motion analysis, videometry.

I. Introduction

Motion analysis has been an area of relevant interest in the last decades (1). Nowadays, we can carry out medical (2) and veterinary studies (3), biomechanical analysis, and diagnosis of diseases in humans (4) and animals (5). To facilitate the kinematic analysis studies, some motion capture systems have been developed (6), which can be classified into 2 types: *on-line systems* (e.*g., Bratrack,* which is a marker-based optical stereo tracking system (7), *Vicon* (8), Impulse (9), and Stage, which does not use markers (10), and the *off-line systems* (e.*g.,* Somcam3D, which is based on passive markers (11), Dvideow (12), SimiMotionCapture3D (13), and Prakash, which uses photo-sensing markers, and does not use cameras (14). Other methods to equine gait analysis are the mathematical models, but in this field we have little background due to its complexity. Some of these models are the quadrupedal gait biomechanics with pendulums (15), and the 3D kinematics of the horses' metacarpophalangeal and interphalangeal joints of forelimbs during walking and trotting, using coordinate systems (16).

There are very few commercial systems to analyze equine gait because, first, most of them are designed for human gait, second, the source code is closed, and third, they are very expensive. Additionally, there are few equine centers that have access to this kind of technology, *e.g.* Horse-racetrack interface (17), Equine Gait Trax Digital Motion Analysis System (18), Qualisys Motion Capute System-Equine Kinematics (19), and Codamotion (20), but they are very few to cover the demand, so in many countries there are veterinarians with many horses, and without the kind of technology necessary to evaluate quantitatively the equine gait.

The main objective of this study was to develop a new motion analysis system based on the videometry technic, which is used to investigate, calculate, and evaluate 2D kinematic parameters of the equine gait. This technic uses mathematical calculations of the kinematic of the horse seen as a mechanical system composed of rigid bodies linked by simple joints. This information can be used to

quantify, analyze, and improve the biomechanics and locomotion performance of the horses (normal or athletic), and determine abnormalities and the need of physical therapy or rehabilitation, among others.

Part I of this paper compares the length of body segments taken manually the length calculated from the equation of the distance between two points (x1, y1) and (x2, y2). The coordinates of these points were obtained through videometry. Part II describes the Graphical Interface developed in Mathematica 7.0 to obtain different parameters for horse gait analysis such as kinematic curves of the main joints, comparisons between kinematic curves of one horse and a normal band of kinematic curves, simulation 2D of the horse movement at different speeds; and a final report with value information of horse gait analysis.

II. Materials and methods

Currently, veterinarians perform motion analysis either subjectively (visually), using all their knowledge and experience in the field of veterinary, or quantitatively (videometry), using high-speed cameras and image processing software. Obtained with the second technique, more specific information about the motion.

To identify how different are the measurement take manually by the veterinaries, the calculated by mathematical equations, and the software of motion analysis, it was realized this study. Next, the comparison between the results of equine kinematics obtained using experimental measurements of horse body length (by measuring tape) and the articular angles (by manual goniometer); the mathematical calculations of body length (by the equation of the distance between two points) and the articular angles (calculated law of cosines) of the entire locomotor system of horses, and the results obtained by a commercial software of motion analysis of horses (TEMA Motion) are shown below. This comparison will allow us to identify how different are the results, and how similar are the curves generated by the mathematical calculations, as well as to determine how this tool can be useful for clinical use.

Study Subjects. In this study, we used 15 Warmblood breed jump horses (10 males and 5 castrated males) that belong to the stables of the Presidential General Staff (México D.F.). The average age of the horses was 9.7 years, the average weight was 521.3 kg, and the average height at the withers was 1.66 m. All horses were raised under the same feeding and training conditions, and were healthy with no signs of lameness, or musculoskeletal disorders.

Horse Weight Estimation The weight of each horse was calculated using equation (1)[21]:

$$Weight(Kg) = \frac{PT\,(cm)^2 * L\,(cm)}{11900} \quad (1)$$

Where *PT* is the thoracic perimeter (heart girth), and *L* is the body length (from point of shoulder to point of hip) (Fig. 1) (21).
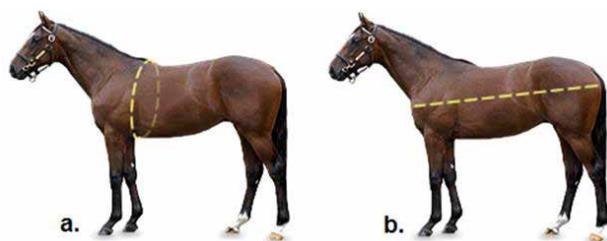

Fig. 1. a. PT: Heart girth measure b. L: Body length measure.

Measurement of Body Segment Lengths: We adhered 17 markers onto the horse's skin at anatomical points (22) (Fig. 2), and then, we measured the body segments.

Direct measurement: The height at the withers (from the ground, in right angle, to the upper portion of the withers) was measured employing a hipometer. The body segments (Fig. 2) were measured using a standard tape (from center to center of each marker).
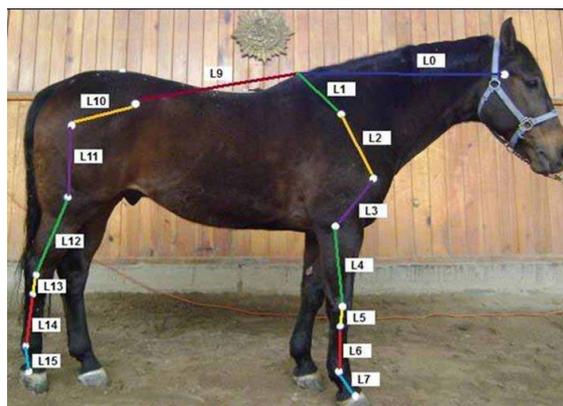

Fig. 2. Body segments used in this study: L0. Neck, L1. Withers – tuber spina scapulae, L2. Tuber spina scapulae Scapula-tuberculum major humerus, L3. Arm, L4. Forearm, L5 Carpus, L6. Fore cannon, L7. Fore pastern, L9. Back, L10. Pelvis, L11. Thigh, L12. Leg, L13. Hock, L14. Hind cannon, and L15. Hind pastern.

Measurement by videometry: High-speed (200 frames/second) StreamView LR cameras, placed at the same distance from the horses, videotaped the equine gait. The interface employed the coordinates of each marker (obtained by processing the videos in the software TEMA 3.0) on the first video frame, and the equation (2) of distance between two points to determinate the lengths of all body segments (L0-L15) (Fig. 2) (Table 1).

$$d = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2} \quad (2)$$

Measurement of Angular Motions: Before the test, each equine (with the markers placed onto their skin (Fig. 2) (23) walked for a pair of minutes to regularize their gait. After that, each horse was placed atop a horizontal surface, walked (hand-led walk), and videotaped for 5 passes with a high speed video camera. Subsequently, from the videos, the coordinates of each marker from all the gait cycles were obtained through the TEMA 3.0 software. After obtaining this information, the angle of each horse's joints was calculated in the Mathematica 7.0 software using the equation of distance between two points –equation of the Law of Cosines– (Fig 3.), and a representation of the horse as a mechanical system of rigid bodies

articulated by simple joints (close chain) (Fig. 4). To calculate the angular movement of each joint of interest, the locomotor system of the horse was considered a series of rigid rods with adjacent segments articulated (linked) by frictionless hinge joints[23].
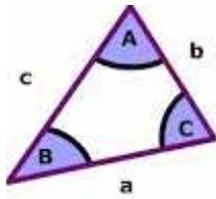
$$a^2 = b^2 + c^2 - 2bc * \cos (A) \qquad (3)$$

$$b^2 = a^2 + c^2 - 2bc * \cos (B) \qquad (4)$$

$$c^2 = b^2 + b^2 - 2bc * \cos (C) \qquad (5)$$
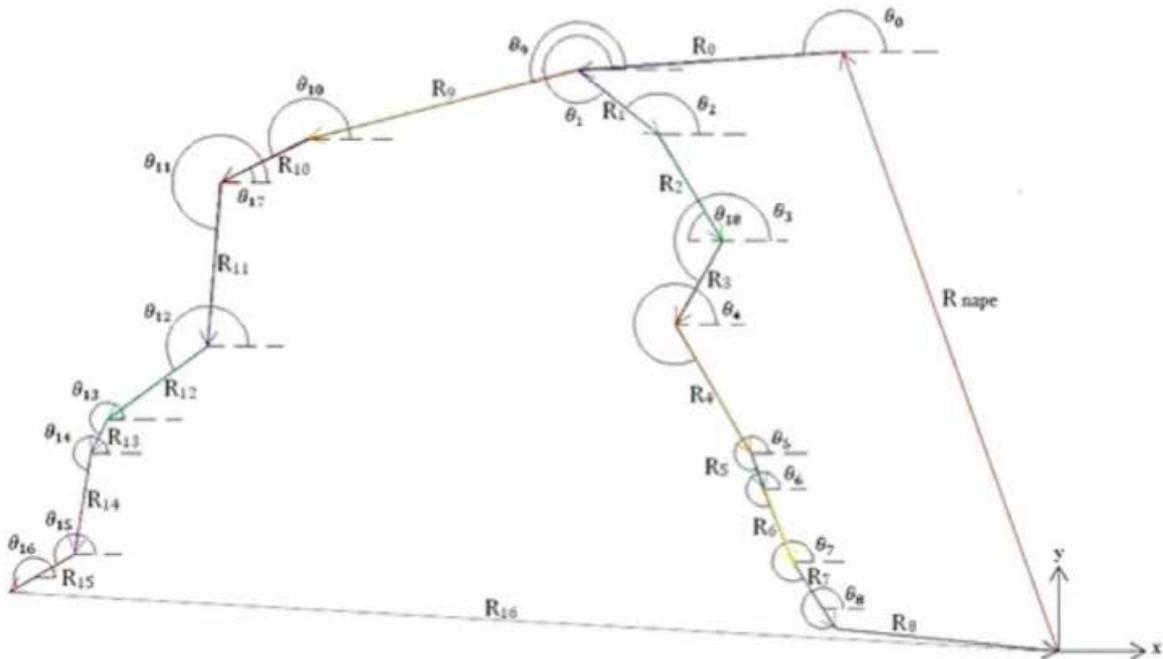
Fig. 3. Law of Cosinis.

Fig. 4. Body segments *vs.* the horizontal axis angles and configuration of the vectorial array.

Graphic Interface, Design and Development. The graphical interface (GUI) was designed and developed in Mathematica 7.0® software using mathematical equations of the kinematics of the horse (23), and a program to generate normal bands of horse gait, which facilitates the analysis, evaluation and diagnosis of equine locomotor pattern. This tool allows the user to register general data of a horse in a template, calculate body segment lengths, generate trajectory curves of markers placed onto the horse's skin, simulate the horse's movement, obtain graphics of the angular movements of the joints (Fig. 3), and generate a report (pdf) with all the information, and later with the numerical values of each curve (average values, standard deviation, actual value of each horse, and the difference between this value and the first one).

Graphical Interface User Operation. The interface allows two kinds of kinematic analysis: An individual analysis, and an analysis of horse *vs.* normal bands of horse population (Fig. 3 and 4).

Individual Analysis. To carry out an individual kinematic analysis, it is necessary to complete the following steps: 1) register the horse in the GUI, including owner's name, horse's keeper name, and horse's name, race, gender, age, weight, the raised, the layer, the activity, and particular marks (if it is necessary to specify); 2) import a picture of the horse for a visual reference; 3) import the file (*.csv) with the markers coordinates; 4) indicate the initial row and the final row with values (frames recorded); 5) determine the initial and final frame visually, taking as a reference the first contact of the right hoof, and the next contact of the same hoof respectively[24]; 6) calibrate the videos in TEMA software using the measure of a 30 cm rule located in the floor during the videos; 7) generate the kinematic curves pressing a button; and 8) analyze the curves (Fig. 5).
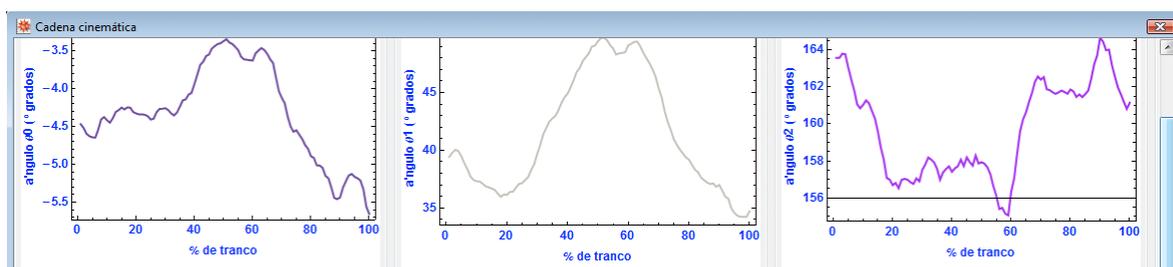

Fig. 5. Individual analysis - kinematic curves of the forelimb.

Analysis of a horse vs. *population.* In this case, first, the user should register the horse and enter general data; then, import the files with the markers coordinates, and the population normal bands; and finally, generate the kinematic curves. Users can select if they want to see the horse line *vs.* max and min of the data, the horse line *vs.* average ± standard deviation, or everything (Figure 6). Users can also observe the horse motion simulation during the analysis, and finally may generate a report file. With this report, users can evaluate qualitatively and quantitatively the horse locomotor pattern, and consult it as often as required.
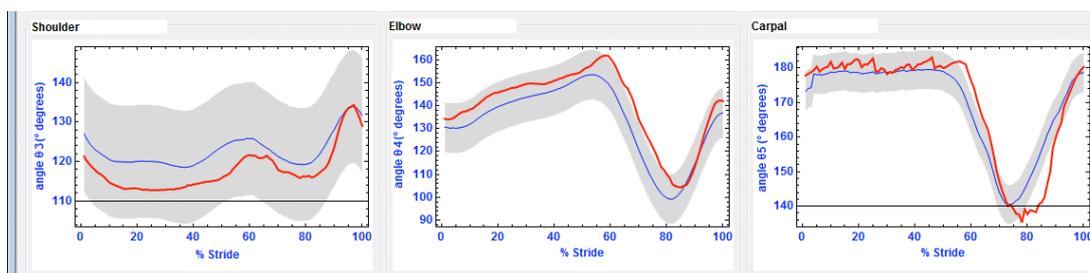

Fig. 6. Kinematic curves of hind-limb joints (horse *vs.* normality band), generated by the GUI.

III. Results

A new GUI was designed and developed programmatically in Mathematica 7.0® software to evaluate and study horse kinematic. This tool allows veterinarians and researchers to compile a general record of evaluated horses, and diagnose qualitative and quantitatively the horse's gait (Figure7).
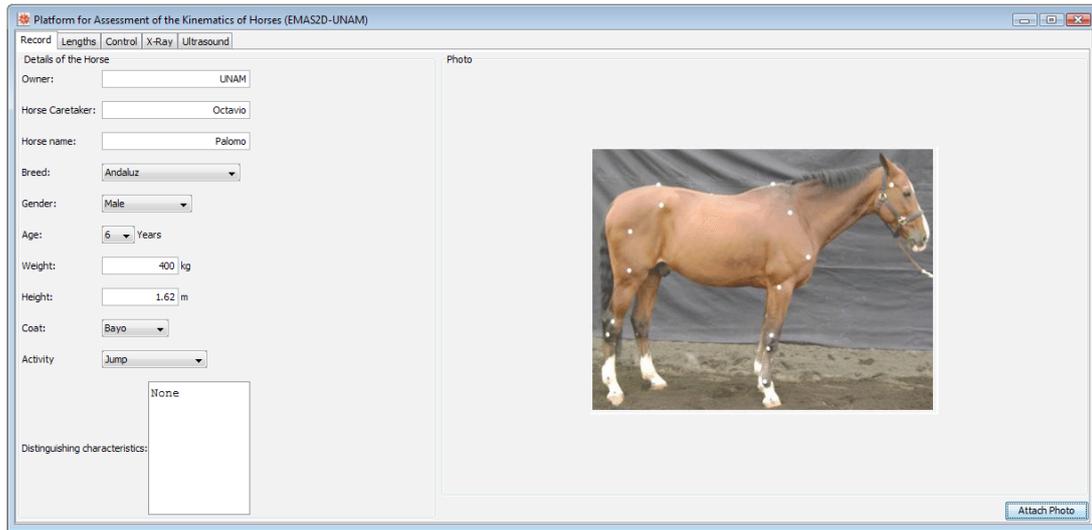
Fig. 7. Graphical user interface home page (register module).

With this GUI, the user can obtain theoretical and experimental measures of the length of body segments, and curves of the trajectory of each marker adhered onto the horse's anatomical landmarks (Table I). The user can also obtain kinematic curves of angular motion (flexion-extension) of each joint of interest to carry out either individual analyses (Figure 8a), or horse *vs.* normality band analyses (Figure 8b). Additionally, the user can obtain a graphical and numerical analysis to individually evaluate each curve *vs.* kinematics band from a normal population (Figure 8c).

Table I. Horse body segments magnitudes.

Body Segment		Av	Dif.	Dev Std.	CV
L0 Neck	E*	90.7	9	4	4
	T**	99.7		11.8	12
L1 Withers – tuber spina scapulae	E	32.5	6.2	3.3	10
	T	26.3		3.9	15
L2 Tuber spina scapula - Tuberculum major humerus	E	33.5	0.4	2.9	9
	T	33.9		3.4	10
L3 Arm	E	29.5	0.4	2	7
	T	29.9		2.9	10
L4 Forearm	E	41.9	1.1	2.2	5
	T	43		4.3	10
L5 Carpus	E	10.6	0.3	0.8	8
	T	10.3		1.2	12
L6 Fore cannon	E	24	0.7	1.1	5
	T	24.7		3.4	14
L7 Fore pastern	E	14.5	0.2	0.5	3
	T	14.3		1.7	12
L9 Back	E	86.4	3.9	4.6	5
	T	90.3		10.6	12
L10 Pelvis (o croup)	E	31.2	0.2	3.1	10
	T	31		3.9	13

Body Segment		Av	Dif.	Dev Std.	CV
L11 Thigh	E	31.8	1.3	3.3	10
	T	33.1		4.6	14
L12 Leg	E	48.4	2.5	3.4	7
	T	45.9		5.5	12
L13 Hock	E	10.8	0.4	1	9
	T	10.4		1.6	15
L14 Hind cannon	E	30.6	0.6	1.1	4
	T	30.1		2.7	9
L15 Hind pastern	E	13.9	0.1	1.8	13
	T	14		1.3	9.2857

E* Values obtained by manual measurement (black numbers) – T** Values calculated in Mathemathica using equation of distance between two points (red numbers) – Av (Average) – Dif. (Difference between the averages of experimental vs. theoretical values) – Dev. Std. (Deviation Standard) – CV (Coefficient of Variation).
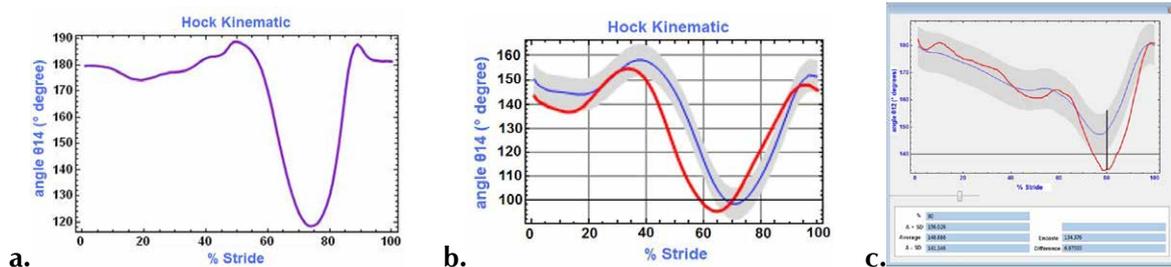

a. **b.** **c.**

Fig. 8. Curve classes generated by the different kinematic analyses
a. Individual; **b**. horse against normality band; **c.** comparative curve.
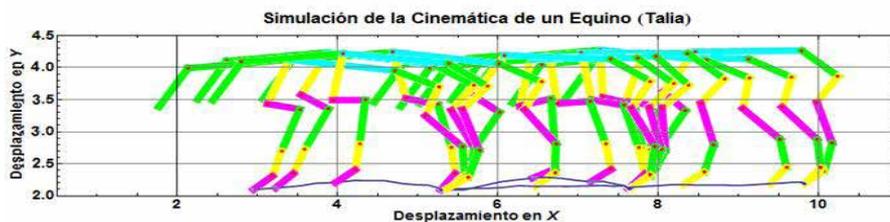

Fig. 9. Fragments of the simulation of the movement of the horse at different speeds.

Another result obtained from the GUI is a simulation of the horse movement at different speeds (Figure 9). In addition, this tool can generate report files with the following information: general data, horse photo, lengths (experimental and theoretical) of body segments, trajectory curves of the markers, joint kinematic curves, and a table with the average values, the average ± standard deviation value, and the difference between them for each horse (values in red mean the horse is out of the normal band) (Figure 10).
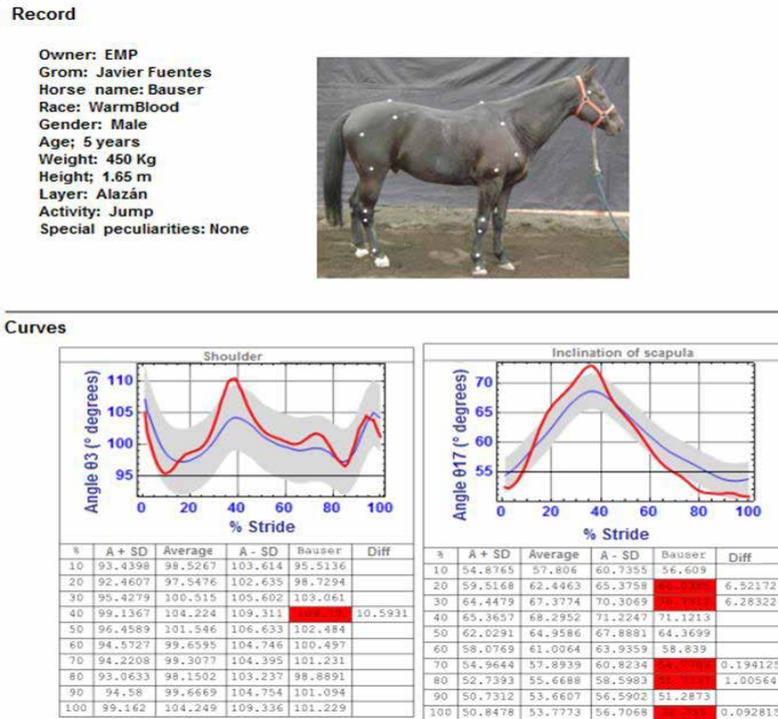
Fig. 10. Report generated (First page) by the GUI.

IV. Discussion and conclusions

If we compare numerically the values of the length of body segments calculated by the interface (theoretical) *vs.* the ones directly measured on the animal (experimental) (Table I), the difference between the average values is small (less than 1 cm), except for the neck length (9 cm), cross-scapula (6.2 cm), back (3.9 cm), and leg (2.5 cm). This is because the experimental measurements were taken with the horse in still position, whereas the values calculated mathematically by the software were obtained with coordinates from the first frame in the equine gait video (dynamic position). To decrease the numerical difference, in future studies, the horse should be videotaped and directly measured at the same still position, hence, a better comparison of these values can be achieved.

This tool facilitates the analysis and improving of movement patterns. For instance, veterinarians using this tool may be able to analyze the movement patterns of horses with lameness better than before, and researchers could be able to look into the motor skills and movement patterns of horses in a much more thorough and objective way than previously. Additionally, this tool may help veterinarians in the following tasks: diagnose the need for surgery, medical treatment, or rehabilitation; evaluate the results before and after a surgery, and track the patient evolution; understand the movement, and the origin and possible causes for dysfunctions or abnormalities; improve performance of athletic horses; evaluate and design more accurate therapeutic shoeing; and analyze how the motion of the horses change on different surfaces. Lastly, the kinematic curves of equines obtained with this mathematical tool are highly similar to the ones generated by commercial software.

The recording (video) of the horse gait, and the report (printed or digital) with the trajectory curves of the anatomical landmarks, kinematic curves of the main joints, horse's ranges of motion

(table and values), and simulation of the animal's movement, obtained from the GUI, will contribute to eliminate the veterinarian's subjectivity during the evaluation, classification, and treatment of lameness and other current diseases. In addition, the video and the report will aid to observe, analyze, and understand the normal and abnormal parameters of equine gait, as well as to identify and learn the specifics of gait anomalies, to understand the effects of different studied diseases; and, finally, they will support the assessment, diagnosis, study, monitoring, and investigation of the kinematics of horses in a qualitative and quantitative way.

On the other hand, this tool allows to add new analysis protocols that ease the gait analysis of other quadruped animals, and the analysis and discussion of other veterinarians' diagnoses about the clinic case of a patient. This can be accomplished at a low cost, and with minimum technological resources and training, only by studying the reports (curves, tables, and simulation) generated by the GUI, and without having to go straight to see the animal. Due to its low costs, this tool may multiply studies with tight budgets, and will make possible to monitor diagnosis and rehabilitation outside the gait laboratory with inexpensive equipment reachable to most vets.

This tool was developed with open source code, and an academic license of Mathematica. Although, the videos were processed with TEMA software, which has a license cost, future studies may use free-software like Kinovea that processes the video to obtain coordinates, trajectories, velocities, and accelerations of the markers of interest. Finally, the interface and the protocol for horse gait analysis are very useful thanks to their versatility; however, to obtain better results, it is necessary to implement an algorithm to identify the initial and the final frame of the gait cycle in Mathematica, use two or three high-speed cameras to register the movement in the three anatomic planes in order to obtain the X, Y, and Z coordinates of each anatomical marker, and reduce the intrinsic errors in the calibration process.

Acknowledgements

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