Equine biomechanical models for three-dimensional kinematics analysis: literature review

Modelos biomecânicos equinos para análise de cinemática tridimensional: revisão de literatura

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ABSTRACT
Three-dimensional analysis in horses has been widely used in the past years due to technological advancement. With the objective of conducting a literature review of the applicability of existing evidence in horses of a biomechanical model focusing on three-dimensional kinematics and its production in Veterinary Medicine, we searched in the databases: ScienceDirect, SciELO and PubMed. To access them, using as key-words: "Three-dimensional kinematic model in equines", "equine kinematic analysis", "biomechanics of equine locomotion", "equine kinematic model". Selection criteria were papers published between: paper published between 1990 and 2020, in English, with free electronic access and in which characteristics of a three-dimensional kinematic model in horses were mentioned. Most studies were experimental, and population included both healthy horses and pathological ones. Three-dimensional kinematic model was used mainly to understand the analysed movement and using as model the full body. There is scientific evidence on the use of biomechanical models for three-dimensional kinematic analysis in horses published in the period studied, used by professionals in veterinary medicine. The objectives of using the model were specific to the type of movement or pathology of the horse and consistent with the characteristics of the studies.

Keywords: Veterinary – Equine modelling, Equine biomechanical models, Equine three-dimensional kinematics, Equine locomotion,

RESUMO
A análise tridimensional em cavalos tem sido amplamente utilizada nos últimos anos devido ao avanço tecnológico. Com o objetivo de realizar uma revisão da literatura sobre a aplicabilidade das evidências existentes em cavalos de um modelo biomecânico com foco na cinemática tridimensional e sua produção em Medicina Veterinária, buscamos nas bases de dados: ScienceDirect, SciELO e PubMed. Para acessá-los, utilize como palavras-chave: "Modelo cinemático tridimensional em equinos", "Análise cinemática

equina", "Biomecânica da locomoção equina", "Modelo cinemático equino". Os critérios de seleção foram artigos publicados entre: artigo publicado entre 1990 e 2020, em inglês, com acesso eletrônico gratuito e em que fossem mencionadas características de um modelo cinemático tridimensional em cavalos. A maioria dos estudos era experimental e a população incluía cavalos saudáveis e patológicos. O modelo cinemático tridimensional foi utilizado principalmente para a compreensão do movimento analisado e usando como modelo o corpo inteiro. Existem evidências científicas sobre a utilização de modelos biomecânicos para análise cinemática tridimensional em cavalos publicadas no período estudado, utilizados por profissionais da medicina veterinária. Os objetivos da utilização do modelo eram específicos ao tipo de movimento ou patologia do cavalo e consistentes com as características dos estudos.

Palavras-chave: Veterinária - Modelagem Equina, Modelos biomecânicos Equinos, Cinemática Tridimensional Equina, Locomoção Equina,.

1 INTRODUCTION

The study of equine locomotion is of great economic importance, since the biggest problems of low performance in horses, especially in sports, are related to the locomotor apparatus (Back, Clayton 2013). In recent years, the analysis of movement in horses has been facilitated due to technological advances in video equipment and computers, however it still falls short of the evolution of research carried out in movement analysis in humans (Barrey 1999).

The biomechanics of the equine movement, on diagnostic medicine, gathers most studies related to the theme. In various sports activities, the horse starts early in intensive work. For younger animals, motor activity and activity routine are essentially traumatic and unnatural from a physiological point of view (Chateau *et al*. 2009). Understanding how these problems directly affect the performance of horses, making a good diagnosis and proper treatment is essential.

In horses, the development of motion analysis systems is achieved with the use of high-resolution cameras and films, combined with optical and computational methods. These methods offer diagrams and graphs whose results can be used to evaluate the improvement of the animal's physical training, helping to obtain better results in sports competitions. Also, they contribute to the diagnosis of locomotor disorders, in addition to offering preliminary data that can be used in animal recovery assessments (Fredricson *et al.* 1980; Back *et al*. 1993). Most of the work carried out with movement analysis in horses uses a high-performance treadmill to ensure uniformity in the type of Type of ground surface, in gait cycles, speed and environmental conditions.

Objective evaluations of the movement of horses using kinematics methods aim to promote an evidence-based clinical decision process, considering the limitations associated with the visual subjective verification of the movement that leads to interpretation bias and disagreements between observers (Keegan *et al*. 1998; Arkell *et al.* 2006; Fuller *et al*. 2006; Hewetson *et al.* 2006).

In this study literature review study was carried out to synthesize the existing evidence on applicability of three-dimensional kinematic models in veterinary clinical practice, aiming to verify the existing evidence on usefulness of these methodologies in horses.

2 METHOD

We conducted a literature review study, developed with the purpose of gathering and synthesizing findings from studies carried out, using different methodologies, to contribute to the deepening of knowledge related to the investigated theme (Soares et al., 2014).

Study description

The review was carried out through the database: PubMed, ScienceDirect, Scielo from the 1990 to 2020. The literature review process took place in six stages, (Moher et al., 2015), as detailed below.

1st Phase: elaboration of the guiding question. At this stage, the following question was defined which the research set out to answer: "What is the importance of using a three-dimensional kinematics model to analyze the movement of healthy horses but with pathologies of the skeletal muscle system?". Considering this question, it was determined which studies were to be included, the means adopted for the identification and the information collected from each selected study.

2nd Phase: search for sampling in the literature. In this phase the research in the databases data established according to the guiding question, considering the participants, the three-dimensional kinematic model used and the variables of interest.

3rd Phase: data collection. In this phase data were extracted from the papers selected).

4th Phase: analysis of the included studies. In this phase the data from the research and characteristics of each study selected in the previous phase.

5th Phase: discussion of the results. In this step the comparison of the data occurred evidenced in the analysis of the articles, possible gaps in knowledge were identified, and it was possible to define priorities for future studies.

6th Phase: presentation of the review (results presentation phase). To support this study, we sought to identify, analyze, and synthesize the evidence available in the literature on the knowledge of veterinary medicine about the use of three-dimensional kinematic models in horses.

The descriptors “Three-dimensional Kinematics Model in Equines”, “Equine Kinematics Analysis”, “Equine Locomotion Biomechanics”, “Equine Kinematics Model” were used. The search and selection of studies took place from July to December 2020, through online access, where the following inclusion criteria were used: full and available papers that met the guiding question, written in English, available in the database of free access online data published since 1990.

Initially, papers were selected and analyzed by reading the title and summary of publications, and studies that specifically addressed the theme of the guiding question were considered eligible.

After this evaluation, the papers included were read in full. Two data collection instruments were developed to analyze and summarize the selected papers. The instruments have information about author, year, type of three-dimensional model used, number of infrared cameras, population, variables analyzed and conclusion.

Inclusion and exclusion criteria

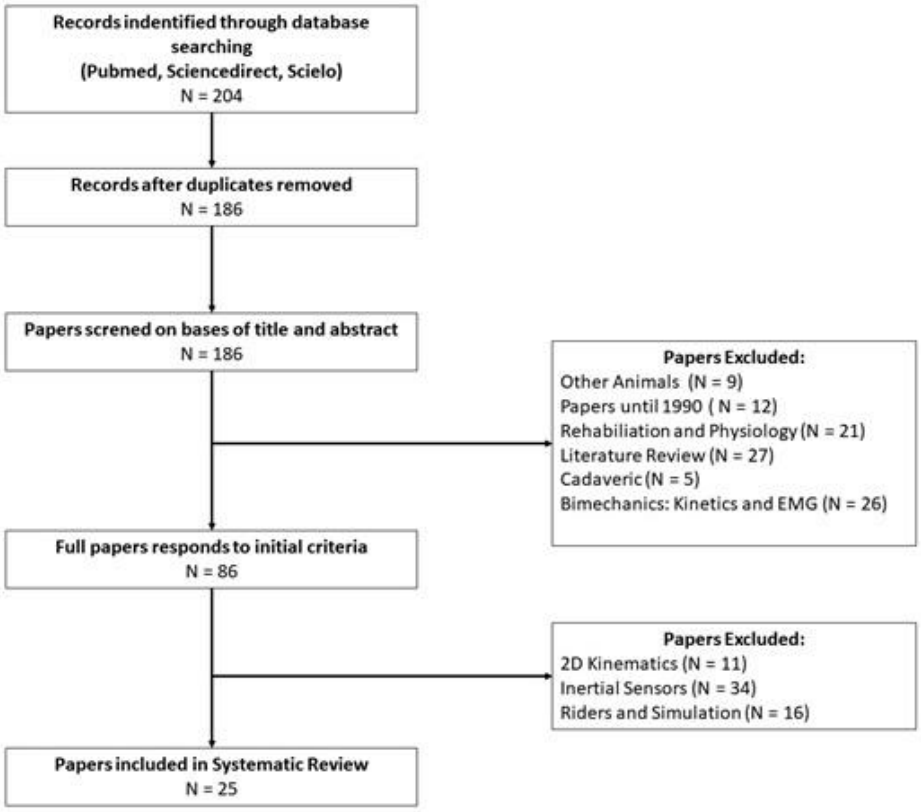
The inclusion criteria used to conduct the research were: articles that answer the guiding question of the research, that were included in the period 1990 - 2020, that were available for free, electronically, complete, in full and that were in the English language.

The exclusion criteria employed were that, although scientific research was found using the requested keywords, after the interpretative reading they did not show correlation with the descriptors: “Three-dimensional Kinematics Model in Equines”, “Equine Kinematics Analysis”, “Equine Locomotion Biomechanics "," Equine Kinematics Model "were used, the study was carried out from July 2020 to December 2020.

Data analysis

Searching for studies with crossing of descriptors, a total of 186 papers were found. After the filters were published: full text available, English language and PubMed, ScienceDirect, Scielo database, a total of 86 papers remained. According to the available abstracts, based on the inclusion criteria, which was to answer the guiding question, only 25 papers were included, so the final sample consisted of 25 papers. The data for each publication was extracted and inserted into a reference management system Mendeley and tabulated in Microsoft Excel (2019), as shown in figure 1.

Figure 1 - PRISMA diagram for obtaining the literature_Source ScienceDirect, SciELO and PubMed



Ethical aspects

Ethical aspects were respected as regards the reliability of the data and authors found in the papers that are part of the analyzed sample.

3 RESULTS AND DISCUSSION

In the search for studies with the crossing of descriptors, a total of 186 articles were found. After applying the filters: full text available, English language and PubMed database, ScienceDirect, Scielo, a total of 86 papers remained. According to the available

abstracts, based on the inclusion criteria, only 25 papers were included, so the final sample consisted of 25 papers. Table 1 shows the characteristics of the 25 papers selected for review. Papers were sequenced to facilitate the construction of tables, the characteristics are author, paper title, year, and publication journal.

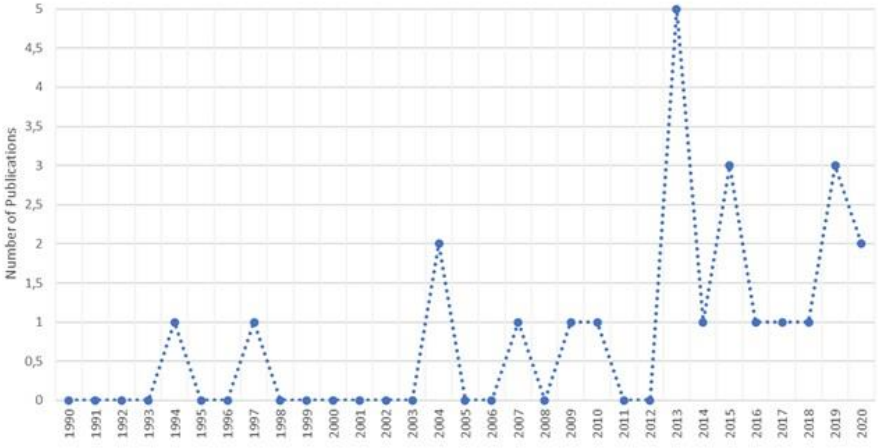
Table 1 - Reference to the studies included in this paper.

AUTHOR	TITLE	YEAR	JOURNAL
Hardeman *et al.*	Range of motion and between-measurement variation of spinal kinematics in sound horses at trot on the straight line and on the lunge	2020	Plos One
Ericson *et al.*	The effect of kinesiotape on flexion-extension of the thoracolumbar back in horses at trot	2020	Animals
Hardeman *et al.*	Variation in gait parameters used for objective lameness assessment in sound horses at the trot on the straight line and the lunge	2019	Equine Veterinary
Hobbs, Clayton,	Collisional mechanics of the diagonal gaits of horses over a range of speeds	2019	PeerJ
Seino *et al.*	Three-Dimensional Kinematic Motion Analysis of Shivers in Horses: A Pilot Study	2019	Equine Veterinary Science
Byström *et al*	Biomechanical findings in horses showing asymmetrical vertical excursions of the withers at walk	2018	Plos One
Holt *et al.*	A simple method for equine kinematic gait event detection	2017	Equine Veterinary
Hobbs *et al.*	An exploration of the influence of diagonal dissociation and moderate changes in speed on locomotor parameters in trotting horses	2016	PeerJ
Starke, Clayton	A universal approach to determine footfall timings from kinematics of a single foot marker in hoofed animals	2015	PeerJ
Brown *et al.*	Swing phase kinematics of horses trotting over poles	2015	Equine Veterinary
Wiggers, *et al.*	Functional locomotor consequences of uneven forefeet for trot symmetry in individual riding horses	2015	Plos One
Hobbs *et al.*	The effect of centre of mass location on sagittal plane moments around the centre of mass in trotting horses	2014	Journal of Biomechanics
Walker *et al.*	Effect of a Pessoa training aid on temporal, linear and angular variables of the working trot	2013	Veterinary Journal
Nauwelaerts *et al.*	Spatio-temporal gait characteristics during transitions from trot to canter in horses	2013	Zoology

Weishaupt *et al.*	Effects of shoeing on intra- and inter-limb coordination and movement consistency in Icelandic horses at walk, tölt and trot	2013	Veterinary Journal
Solé *et al.*	Kinematic Characterization of the Menorca Horse at the Walk and the Trot: Influence of Hind Limb Pastern Angle	2013	Equine Veterinary Science
Hobbs, Clayton	Sagittal plane ground reaction forces, centre of pressure and centre of mass in trotting horses	2013	The Veterinary
Unt *et al.*	Variation in frontal plane joint angles in horses	2010	Equine Veterinary
Chavaunne *et al.*	Transverse and dorso-ventral changes in thoracic dimension during equine locomotion	2009	Veterinary Journal
Gómez *et al.*	The effect of induced forelimb lameness on thoracolumbar kinematics during treadmill locomotion	2007	Equine Veterinary
Bobbert *et al.*	Validation of vertical ground reaction forces on individual limbs calculated from kinematics of horse locomotion	2007	Journal of Experimental Biology
Chateau *et al.*	Evaluation of three-dimensional kinematics of the distal portion of the forelimb in horses walking in a straight line	2004	American Journal of Veterinary Research
Khumsap *et al.*	Three-dimensional kinematic analysis of horses with induced tarsal synovitis	2004	Equine Veterinary Journal
Pourcelot *et al.*	Kinematics of treadmill versus overground locomotion in horses.	1994	The Veterinary quarterly
Buchner *et al.*	Kinematic Symmetry Index: A method for quantifying the horse locomotion symmetry using kinematic data	1997	Veterinary Research

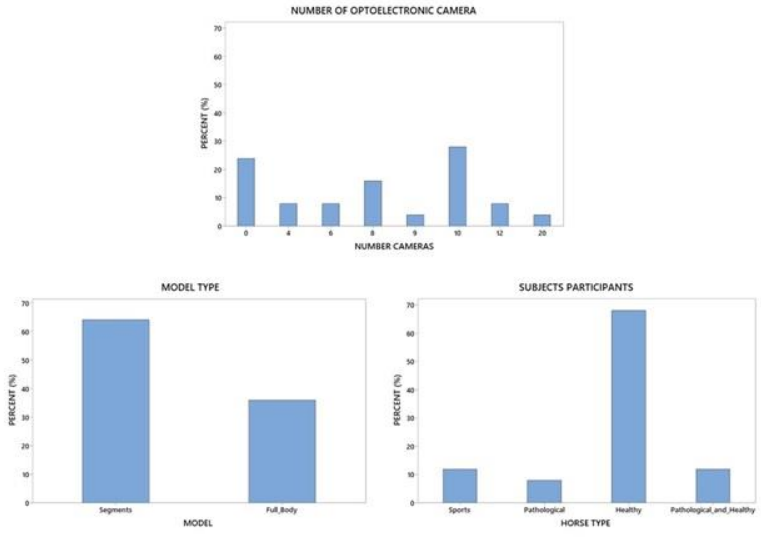
The number of publications over the years is irregular, as shown in Figure 2. No explanations were found for the publication peaks in some years (2013, 2015 and 2019) and the drop in others (2003 and 2005) and even the non-publication in some periods (1990 to 1993, 2000 until 2004, 2005 and 2006, 2008, 2011 and 2012). In general, there is an increase in the number of publications in the last seven years (from 2013). The reduced number of articles in 2020 is explained by the fact that some articles had already been registered in some databases after the end of the selection of papers in this study.

Figure 2 - Graph of the number of publications per year_Note n = 25 and data from the last 30 years_Source ScienceDirect, SciELO and PubMed



The results of this review showed great diversity in relation to the three-dimensional kinematic model. Most studies used the segmental model (65%), followed by the full body model (35%). Figure 3 shows the percentage regarding the amount of use of optoelectronic cameras, type of model (segmented or full body) and studied population. Table 2 presents the characteristics of three-dimensional kinematic models: number of cameras, type of model (segmented or full body), population studied, and variables analyzed.

Figure 3 - Graph of the percentage of the amount of use of optoelectronic cameras, type of model and population studied



As a curious fact and when we look in detail at table 2, which refers to characteristics of three-dimensional kinematics protocols, we observe that the three-dimensional kinematic model appears only in 1994. It is important to highlight how most investigations analyzed show positive results about the use of three-dimensional

kinematic models, thereby gaining a global perspective of its effectiveness as a complementary diagnostic tool for analyzing movement in horses.

Table 2 - Characteristics of three-dimensional kinematics protocols

AUTHORS	YEAR	NUMBER OF OPTOELECTRONIC CAMERAS	MODEL TYPE	POPULATION	VARIABLES
Hardeman *et al.*	2020	Not reported	Segment	Sport Horse	Linear, temporal kinematics Spine Flexion and Extension
Ericson *et al.*	2020	20	Segment	Horses with pathologies	Linear, temporal kinematics Trunk flexion and extension
Hardeman *et al.*	2019	Not reported	Segment	Sport Horse	Symmetry of the Segments
Hobbs, Clayton,	2019	10	Full body	Healthy horse	Slope of Forelimb and Hindlimb
Seino *et al.*	2019	8	Full body	Healthy horse Horses with pathologies	Linear, temporal kinematics Hoof elevation and centroid
Byström *et al.*	2018	12	Full body	Healthy horse	Forelimb and Hindilimb Protraction and Retraction
Holt *et al.*	2017	10	Segment	Healthy horse	Joint Center Velocity and Displacement of joints Distal metacarpophalangeal and interphalangeal
Hobbs *et al.*	2016	10	Segment	Healthy horse	Linear, temporal kinematics Behavior COM
Starke, Clayton	2015	8	Segment	Healthy horse Horses with pathologies	Hoof dorsal angle
Brown *et al.*	2015	10	Full body	Healthy horse	Linear, temporal kinematics Flexion and extension of Forelimb and Hindlimb joints
Wiggers *et. al.*	2015	8	Segment	Healthy horse	Dorsal hoof wall angle
Hobbs *et al.*	2014	10	Full Body	Healthy horse	Sagittal-plane momentsaround the COM

Walker *et al.*	2013	Not reported	Segment :	Healthy horse Horses with pathologies	Tarsal joint behavior
Nauwelaerts *et al.*	2013	10	Full body	Healthy horse	Tarsal joint behavior Hindlimb e Forelimb
Weishaupt *et al.*	2013	9	Segment :	Healthy horse	Linear, temporal kinematics
Solé *et al.*	2013	Not reported	Segment	Healthy horse	Linear, temporal, and angular kinematic characteristics
Hobbs, Clayton	2013	10	Full Body	Healthy horse	Linear, temporal kinematics Behaviour COM
Unt *et al.*	2010	8	Full Body	Healthy horse	Angle for carpus, tarsus, MCP and MTP joints
Chavaunne *et al.*	2009	4	Segment	Healthy horse	Back Diameter, Back Displacement
Gómez *et al.*	2007	6	Segment	Healthy horse	flexion, extension, and rotation of the sacral joint
Bobbert *et al.*	2007	12	Segment :	Healthy horse	Linear, temporal kinematics
Chateau *et al.*	2004	Not reported	Segment :	Sport Horse	Behavior of the distal metacarpophalangial joint
Khumsap *et al.*	2004	6	Segment :	Healthy horse	Flexion and Extension of the tarsal and metatarsal joint
Pourcelot *et al.*	1997	4	Segment :	Horses with pathologies	Symmetry index
Buchner *et al.*	1994	Not reported	Segment :	Healthy horse	Linear, temporal kinematics

According to Hobbs et al. (2010), although two-dimensional analysis of equine locomotion is increasingly used as a diagnostic analysis tool. Three-dimensional analyzes are used as a complex research tool that assists in clinical trials and possible treatments. However, the development of three-dimensional analysis of the movement of horses is pursued, to evaluate the improvement of physical training of the animal, helping to obtain better results in sports competitions and in the daily clinic activity. This methodology, using three-dimensional analysis and three-dimensional models, contribute to the

diagnosis of locomotor disorders, in addition to offering preliminary data that can be used in animal recovery assessments (Back *et al*. 1993).

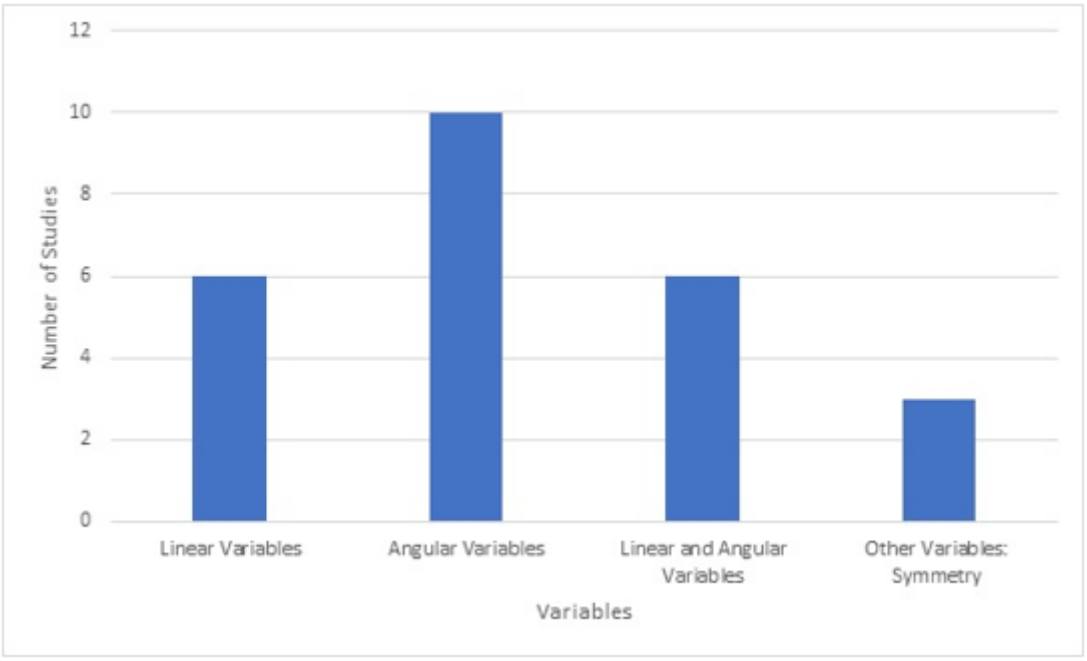
There was a great diversity regarding the use of a three-dimensional kinematics model by several studies in the equine veterinary area, most of which were used in three-dimensional kinematic models, but few full-body kinematic models were used. The population studied was healthy, pathological, and Sports' horses, with healthy horses predominating for development of protocols for assessing the movement of the horse.

The three-dimensional analysis uses multiple cameras that must be perfectly synchronized. Each marker must be visible for at least two cameras each range of time depending on the frequency of data recording (Clayton, Schamhardt 2013), to be able to spatially reconstruct their positions (Morris, Lawson 2010).

Currently, the most used method for locomotion analysis in horses are those based on optoelectronic systems (Barrey 1999; Geiger, Hagen 2018; Hobbs *et al*. 2010), depending on the placement of markers on the horse's skin over known anatomical regions (Langlois *et al*. 1978; Weller *et al.* 2006). The markers used are passive, coated with a material that reflects incident light (Degueurce *et al.* 1996; Clayton, *et al.* 2007). For a three-dimensional reconstruction, at least four optoelectronic cameras are generally used. In this review, studies show a diversity in terms of the number of cameras for three-dimensional reconstruction, as shown in table 3, the studies analyzed here present a minimum of 4 cameras (Pourcelot *et al.* 1997; Chavaunne, *et. al.* 2009; Janura *et. al*. 2010) and a maximum of 20 cameras (Ericson *et al*. 2020). However, despite carrying out studies using three-dimensional kinematic models, 6 studies do not report the number of cameras they used (Hardeman *et al.* 2020; Hardeman *et al*. 2019; Walker *et al*. 2013; Solé *et. al*. 2013; Chateau *et al*. 2004; Buchner *et al.* 1994).

Regarding the kinematic variables analyzed, as can be seen in the graph in figure 4, it was found that 10 studies use angular variables, 6 studies use 6 variables, and 6 studies use the linear and angular variables together.

Figure 4: Graph of the kinematic variables analyzed in the publications



Kinematics variables are involved in describing the movement, regardless of the forces that cause it. It includes linear and angular displacement, velocity, and acceleration. Displacement data refer to anatomical and morphological references such as: center of mass of body segments, center of joint rotation, extremities of limbs or anatomical prominences (Winter 2009; Bobbert et al. 2005). These variables contain essentially the same information that is presented to human eyes, the difference is in the quantitative nature of the information and the high spatiotemporal resolution. This resolution is important because small or rapid changes in movement can be invisible to the human eye (Meershoek,2001). Therefore, the studies presented in table 3, present all the variables commonly analyzed.

The three-dimensional kinematics quantifies the characteristics of the movement that are evaluated qualitatively during a visual examination. It is made through temporal, linear, and angular measurements and describe the movement of body segments and joint angles. The research studied in this systematic review presents two types of models. As mentioned above, 10 studies present the full body model and 15 the segmented model. This great difference in studies using the segmented model, occurs because studies in horses are usually concerned with analyzing specific regions as a way of complementing the diagnosis of musculoskeletal pathologies or even their contribution to the understanding of the analyzed movement.

In summary, this study did not observe how, over the years, the research work gained greater precision and better exploitation of the kinematic data (through the analyzed variables), allowing greater reach and applications in later studies.

The methodological procedures used in this article had an emphasis on the study of literature review. This practice, in addition to assisting in mapping the portfolio of articles, provided, in a systematic way, the acquisition of a part of scientific knowledge on the topic of using three-dimensional kinematic models for analyzing the movement of horse walking.

Another factor that justifies the use of a literature review to conduct research is mainly based on the ability of this mapping to enable and assist the synthesis and analysis of the knowledge existing in the scientific literature on an investigated topic. Another detail refers to the fact that this analysis allows obtaining information that readers to assess the relevance of the procedures used in preparing the review.

In the case of this article, the search for understanding about the use of three-dimensional kinematic models in horses, with the definition of criteria for conducting the search, resulted in a portfolio of 25 articles, which expanded the knowledge about the panorama of scientific production on the subject, but emphasizing that the special focus of the type of model used. Therefore, the proposed taxonomy for the segmentation of articles stands out as a contribution to the study. In this sense, taxonomy has allowed to categorize a set of information, previously dispersed and now possible to be analyzed and made known to the area of analysis of movement in horses. Thus, it is considered that the study contributes: (i) by highlighting ideas and their management as an emerging theme in the context of research on three-dimensional kinematic model in horses; (ii) when identifying the three-dimensional kinematic model to obtain kinematic analysis variables.

4 CONCLUSION

This review summarized published research on biomechanical models for three-dimensional kinematics analysis in horses, within the period of 1990-2020, and gives evidence of its impact when used by professionals in Veterinary Medicine. Assessed publications consulted have focused on factors that can easily promote the reproducibility of the model such as the number of retroreflective markers, its anatomical landmarks, and the development of the model in accordance with the objective of a full body model or a segmental model. The goals of using the model were specific to the type of movement or pathology of the horse and consistent with the characteristics proposed by the studies.

The use of optoelectronic cameras in the data model acquisition offers a contribution to the quantitative and qualitative study of the horse's movement and enable more accurate kinematic data.

In this context, the use of three-dimensional kinematic models that use specific biomechanical methodologies is an adequate tool for assessment the horse movement and it is of great importance in diagnosis and intervention decisions in Veterinary Medicine. Finally, pointing out a more refined in the analysis of relevant articles within of each of the categories, in search of the best understanding of the state of the art and in the search to identify gaps for future research.

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