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Kinematics of the axial segment of horses submitted to dynamic mobilization exercises

Cinemática do segmento axial de equinos submetidos aos exercícios de mobilização dinâmica

Cinemática del segmento axial de los caballos sometidos a ejercicios de movilización dinámica

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Abstract
This study aimed to investigate the kinematic effects of dynamic mobilization exercises on the axial segment in horses. Twelve horses crossbreed were used, which were monitored before (day 0) and at the end of the experimental period (day 120), distributed in an entirely randomized design, totalizing six repetitions per treatment The treatments consisted of two experimental groups, one composed of horses not performing the dynamic mobilization exercises and the other composed of horses submitted to the mobilization program. The static kinematic variables were evaluated, by means of hemispherical markers such as depth (cm), angle (°), difference in depth and angle, for each vertebral level analyzed (T10, T13, T17, L1 and L3), as well as total range of motion for depth and angle, in which this parameter expressed the thoracolumbar motion in its entirety. The performance of dynamic mobilization produced a significant ($P<0.05$) decrease in thoracolumbar depth and increase in thoracolumbar flexion angle, compared to the group that did not perform the functional exercises. A reduction in the total thoracolumbar depth of -6.28 cm ($P<0.0001$) was observed in horses that underwent the exercises. The same response behavior was verified for angular measurement, in which there was an increase in the total ROM of the angle, reflecting thoracolumbar flexion, of 15.54°($P<0.00001$). It was concluded that dynamic mobilization exercises consistently produce flexion of the axial segment, becoming a potential tool to improve range of motion and thoracolumbar function in horses.
Keywords: Spine biomechanics; Horse; Thoracolumbar; Functional training.

Resumo
Este estudo objetivou investigar os efeitos cinemáticos dos exercícios de mobilização dinâmica sobre o segmento axial em cavalos. Foram utilizados doze cavalos mestiços, monitorados antes (dia 0) e ao término do período experimental (dia 120), distribuídos em delineamento inteiramente casualizado, totalizando seis repetições por tratamento. Os tratamentos consistiram em dois grupos experimentais, sendo um composto por cavalos não realizando os exercícios de mobilização dinâmica e o outro constituído por cavalos submetidos ao programa de mobilização. Foram avaliadas as variáveis cinemáticas estáticas, por meio de marcadores hemisféricos como, profundidade (cm), ângulo (°), diferença na profundidade e ângulo, para cada nível vertebral analisado (T10, T13, T17, L1 e L3), bem como amplitude de movimento total para profundidade e ângulo, no qual este parâmetro expressou o movimento da toracolombar por inteiro. A realização de mobilização dinâmica, produziu uma significante ($P<0,05$) diminuição na profundidade da toracolombar e aumento no ângulo de flexão da toracolombar, em comparação ao grupo que não realizou os exercícios funcionais. Observou-se redução na profundidade total da toracolombar, nos cavalos submetidos aos exercícios, de -6,28 cm ($P<0,0001$). O mesmo comportamento de reposta foi verificado para medida angular, no qual ocorreu incremento na ADM total do ângulo, refletindo a flexão da toracolombar, de 15,54° ($P<0,00001$). Concluiu-se que os exercícios de mobilização dinâmica produzem flexão do segmento axial, de forma consistente, se tornando em uma ferramenta potencial para melhorar a amplitude de movimento e a função da toracolombar de equinos.
Palavras-chave: Biomecânica da coluna; Cavalo; Toracolombar; Treinamento funcional.

Resumen
El objetivo investigar los efectos cinemáticos de los ejercicios de movilización dinámica en el segmento axial en caballos. Se utilizaron doce caballos mestizos, monitorizados no día 0 y al día 120, distribuidos en un diseño totalmente aleatorio, totalizando seis repeticiones por tratamiento Los tratamientos consistieron en dos grupos experimentales, siendo uno compuesto por caballos que no realizaron los ejercicios de movilización dinámica y el otro compuesto por caballos sometidos al programa de movilización dinámica. Las variables cinemáticas estáticas se evaluaron mediante marcadores hemisféricos como la profundidad (cm), el ángulo (°), la diferencia de profundidad y ángulo, para cada nivel vertebral analizado (T10, T13, T17, L1 y L3), así como la amplitud total de movimiento para la profundidad y el ángulo, en que este parámetro expresaba el movimiento toracolumbar en su totalidad. La realización de la movilización dinámica, produjo una reducción significativa (P<0,05) en la profundidad toracolumbar y aumento del ángulo de flexión toracolumbar, en comparación con el grupo que no realizó los ejercicios funcionales. Se observó una reducción de la profundidad toracolumbar total de -6,28 cm (P<0,0001) en los caballos sometidos a los ejercicios. El mismo comportamiento de respuesta se verificó para la medición angular, en que hubo un aumento en el ROM total del ángulo, que refleja la flexión toracolumbar, de 15,54° (P<0,00001). Se concluyó que los ejercicios de movilización dinámica producen una flexión consistente del segmento axial, convirtiéndose en una herramienta potencial para mejorar el rango de movimiento y la función toracolumbar en caballos.

Palabras clave: Biomecánica de la columna vertebral; Caballo; Toracolumbar; Entrenamiento funcional.

1. Introduction

Lordosis is a condition of the dorsal region of most concern, which is characterized by an exaggerated curvature of the spine, leading to significant sinking of the thoracolumbar region, with ventral displacement of the spine. This deformity can be primary, when it is congenital or acquired in the first years of life, or secondary, when caused by external factors. According to Gellman (1998), the incorrect adjustment of the saddle and incorrect training may cause muscle atrophy in the withers region. However, it is notorious that all older horses have some degree of secondary lordosis (Denoix, 1999).

Additionally, research has shown that athletic horses, generally exhibit little dorsal movement and great muscular asymmetry, impairing their functional ability (Gómez Álvarez et al., 2007; Gómez Álvarez et al., 2008; Dyson & Greve, 2016). This restriction of dorsal movement is significant in the regions near the withers and in the last thoracic vertebra (T18), which with its evolution results in muscle atrophy, lowering of the spine and, subsequently, claudication (Greve et al., 2017). With the continuation of this condition, it inevitably progresses, to an early retirement from sports activities (Oliveira, 2018). Thus, solutions that prioritize the prevention of dysfunctions and/or the stabilization of the horse spine are indispensable for the well-being and sport longevity of equine athletes.

The benefits of adopting a physical training program based on functional exercises have been widely studied in recent years because they are simple and non-invasive techniques that use the animal's own weight to develop the stability of the core (body strength center) (Oliveira et al., 2015). Among these benefits can be highlighted the increase in balance and flexibility of the animal (Oliveira et al., 2015), muscle hypertrophy (D' Angelis et al., 2004; Stubbs et al., 2011; Tabor, 2015), prevention and rehabilitation of equines with musculoskeletal disorders (Clayton et al., 2012; Oliveira et al., 2015; Clayton, 2011) and improvement in the quality of gait as a whole (Clayton et al., 2012).

Functional movement defined as dynamic, applied in the functional program, used for pain control and dysfunction of the joint, neural and muscular systems (Goff, 2009), has been advocated as a positive intervention to reduce equine low back pain using exercises similar to those applied in humans. Dynamic mobilization exercises is a technique described for use in humans by Petty (2004), but also used regularly in horse rehabilitation. For these animals, the exercises are performed by petting them to be guided to the desired position, causing an elongation of the structures associated with the dorsal spine, such as supraspinatus ligament and epaxial musculature (Haussler, 2009).

Dynamic spinal mobilization is achieved when horses follow a standard controlled movement. This activity consists of performing longitudinal flexion and lateral flexion of the neck and back, while stabilizing the back and limbs to maintain balance. Thus, a large number of muscles are recruited, including the abdominal, epaxial, pelvic, propulsor, and pectoral muscles (Oliveira et al, 2019). This group of exercises increases joint range of motion and strengthens the muscles in which the exercise is associated (Clayton et al, 2012; Rodrigues et al, 2021).

Despite published research using dynamic mobilization exercises in horses, none has investigated the kinematics of the axial segment. Therefore, it was aimed to study the kinematic effects of dynamic mobilization exercises over 120 days on the axial segment in asymptomatic fundamental horsemanship horses. In this sense, this study hypothesized that dynamic mobilization exercises may promote flexion of the spine, through dorsal displacement of the thoracolumbar region, causing kinematic changes in depth, angular and range of motion of the axial segment.

2. Methodology

2.1 Ethical Approval

This research was approved by the “Ethics Committee on the Use of Animals," from the Animal Science Course, São Paulo State University, Dracena Campus, under the protocol number 08/2021/R1, in accordance with the ethical principles of animal experimentation, and it was funded by the Foundation of the São Paulo State Researched FAPESP 2021/02657-3.

2.2 Experimental Design

Twelve horses without defined breed were used, in which they were monitored before (day 0) and at the end of the experimental period (day 120). The criterion for inclusion of horses in the trial was no visible claudication, no signs or symptoms compatible with musculoskeletal injuries, and being used in riding lessons at the fundamental level.

The treatments consisted of two experimental groups, one consisting of horses not performing the dynamic mobilization exercises, referred to as control, and the other consisting of horses undergoing the mobilization program. Thus, the horses were distributed in an entirely randomized design, totalizing in six repetitions per treatment (Oliveira et al., 2015). The dynamic mobilization exercises were performed on the horses three times a week for four months, i.e., requiring a total experimental period of 120 days for completion.

The experimental horses were subjected to a series of dynamic mobilization (DM) exercises consisting of three longitudinal cervical flexions (head on chest, head between carpals, head between hooves), one cervical extension and three lateral cervical flexions (head on shoulder, patella and hock), right and left sides, totaling ten mobilizations according to the methodology of Oliveira et al. (2015). Each mobilization exercise was repeated five times, for each exercise session and done with the aid of a snack, to lead the horses to the desired positions, as well as holding the position for five seconds, plus a 30-second interval between each repetition.

During the experimental period, the horses were kept in a masonry stall with an area of 9 m2, cemented floor covered with bedding, drinking fountain and feeders for consumption of concentrate and mineral salt. Feeding was divided into three equal meals of concentrate and roughage, being offered at 7:00 am, 1:00 pm, and 7:00 pm. The total dry matter intake level was 2.5% of body weight, in a concentrate to volume ratio of 30:70. Diets were formulated to meet the minimum nutritional requirements of horses in moderate work (NRC, 2007).

Physical activity monitored by a trained riding coach was performed daily, five days a week, in an open arena, with a flat sand track, 2.5 - 5.0 cm thick, consisting of mounted activity lasting 1 hour. This mounted work routine was the same developed by the horses for at least three years, and they were adapted to it. Always on weekends, the horses were allowed access to the sand paddock for four hours. The horses were also dewormed with a broad spectrum antiparasitic based on ivermectin, prior to the beginning of the experiment and every three months throughout the experiment.

2.3 Variables and Data Collection

The experimental variables were obtained through two evaluations, the first performed before starting the exercises (day 0), and the second measurement obtained after four months of dynamic mobilization (day 120). Static, linear (depth) and angular kinematic variables of the thoracolumbar region were evaluated by means of hemispherical markers. Hemispherical markers were applied to seven dorsal spinous processes. The dorsal markers were placed at the highest point of the withers, T10, T13, T17, L1, L3 indicated by palpation of the ribs, at the midpoint between the sacral tuberosities (TS), located by palpation of the TS, signaling the spinous process of the first sacral vertebra, according to Figure 1 (Greve & Dyson, 2015).

Figure 1 - Image of the fixation of hemispherical markers on the thoracolumbar of an experimental horse (observe the fixation of the markers from left to right, highest point of withers, T10, T13, T17, L1, L3 and sacral tuberosity).

Source: Authors (2022).

To take the images, each horse was stopped at a station, on a flat, cemented floor, with the head in a neutral position, with the animal's mouth close to the level of the tip of the shoulder. This position was obtained by consistent corrections using halter and rope handle (Berner et al., 2012). Photographic images of the horses, were taken using an iPad mini (Apple iPad mini model A1432, Apple, Cupertino, CA, USA). The iPad was attached to a tripod placed at a height of 120 cm and 3 m laterally and perpendicular to the left side of the horse. Also. a vertical strip, in red color, measuring 1 m was placed on the image plane to serve as a reference point to create a scale for measurement, which was calculated during subsequent digital analysis (Figure 1) (Taylor et al., 2019).

Digital analysis of the images was performed with the aid of Corel Draw software (version X7), in which it was possible to measure the static kinematic variables such as, depth (cm), angle (°), difference in depth (cm) and difference in angle (°), for each vertebral level analyzed (T10, T13, T17, L1 and L3), as well as the total range of motion (ROM) of the thoracolumbar spine, for depth and angle, in which this parameter expressed the total movement of the spine, in flexion or extension (Dyson et al. , 2011).

For depth measurement, a horizontal line was drawn from the marker at the withers to the marker positioned between the TS, then vertical lines were plotted, for each thoracolumbar marker (T10 to L3), meeting the horizontal line, making it possible to obtain the individual depth measurement for each marker (T10 to L3). The difference in depth of the thoracolumbar region was calculated by subtracting the values obtained on day 120 and day 0 of the trial (final evaluation - initial evaluation), individually for each marker from T10 to L3.

Thoracolumbar angles were also measured by plotting a straight line from the marker at the withers to the individual marker of interest (T10 or T13 or T17 or L1 or L3) and a second straight line plotted from this point of interest to the TS to allow the angle to be measured (Tabor & Randle, 2013).

Similarly, to the measurement of the difference in depth, the difference in thoracolumbar angle was obtained by subtraction between images taken on day 120 and day 0 of the trial (final assessment - initial assessment), individually for each marker from T10 to L3. Thus, negative values for depth difference express the dorsal displacement of the spine, indicating flexion movement of the spine. Negative values for angular difference demonstrate spinal movement in extension, while positive results indicate spinal flexion. Moreover, the sum of the difference obtained for each thoracolumbar marker (T10 to L3) was calculated for depth and angle, thus obtaining the total ROM of the thoracolumbar spine, expressed in centimeters and degrees, respectively.

2.4 Statistical Analysis

The kinematic data of the horses' spine are presented as mean, with standard deviation (±d.p.) as a measure of dispersion. The variables were evaluated for normality of distribution using the Kolmogorov-Smirnov test. For data with normal distribution, analyses were conducted using ANOVA (SAS, 2000) to identify significant effects between the two experimental groups for the difference in depth and angle for each thoracolumbar marker, as well as the mean total ROM for depth and angle. Statistical tests used 5% probability.

3. Results

Performing dynamic mobilization in fundamental riding horses produced a significant ($P<0.05$) decrease in thoracolumbar depth and increase in thoracolumbar flexion angle, compared to the group that did not perform the functional exercises (Tables 1 and 2). The significant differences observed were consistent for each level of the thoracolumbar markers (Tables 1 and 2). A reduction in the total thoracolumbar depth (sum of the difference of all points studied) of -6.28 cm ($P<0.0001$) was observed in horses submitted to the exercises when compared to the control group, indicating an increase in the total ROM of the spine in flexion. The same response behavior was verified for angular measurement, in which there was an increase in the total ROM of the angle, reflecting the thoracolumbar flexion, of 15.54° ($P<0.00001$), favorable to the dynamic mobilization group. The differences in thoracolumbar flexion angle between the experimental groups were 3.3 degrees at T10, 3.5 degrees at T13, 3.0 degrees at T17, and 3.2 and 2.6 degrees for L1 and L3, respectively (Table 2).

Table 1 – Mean and standard deviation (±) of initial, final measurements and differences in thoracolumbar depth (cm)[1] of horses submitted or not submitted to dynamic mobilization exercises.

Marker	Control			Dynamic Mobilization		
	Initial	Final	Diference[2]	Initial	Final	Diference
T10	8.57±0.82	9.27±01.14	0.70±0.81^{b}	8.29±2.12	7.26±2.26	-1.04±1.57^{a}
T13	10.29±1.22	10.60±1.30	0.32±0.16^{b}	10.84±1.34	10.13±1.12	-0.71±0.42^{a}
T17	8.14±1.24	8.57±1.59	0.43±0.72^{b}	9.41±0.86	8.56±0.68	-0.85±0.35^{a}
L1	5.97±0.53	6.46±1.17	0.49±0.70^{b}	7.19±0.52	6.49±0.90	-0.71±0.81^{a}
L3	3.23±0.44	3.63±0.89	0.40±0.59^{b}	3.64±0.28	2.99±0.45	-0.65±0.22^{a}

[1] ANOVA test was used to identify significant differences ($P<0.05$) between the two experimental groups, where values in the row with the same letter do not differ significantly. [2] Difference (final assessment - initial assessment) in thoracolumbar depth was calculated for each axial segment marker. Source: Authors (2022).

Table 2 – Mean and standard deviation (±) of initial, final measurements and angular differences (°)[1] of the thoracolumbar spine of horses submitted or not to dynamic mobilization exercises.

Marker	Control			Dynamic Mobilization		
	Initial	Final	Diference[2]	Initial	Final	Diference
T10	155.13±1.91	153.53±1.62	-1.61±0.77^{b}	153.92±2.12	155.61±2.64	1.69±1.56^{a}
T13	155.49±2.14	153.83±2.09	-1.66±0.68^{b}	152.63±0.47	154.49±0.93	1.86±0.97^{a}
T17	159.73±1.64	158.11±2.53	-1.62±1.18^{b}	157.90±0.84	159.24±1.29	1.35±1.02^{a}
L1	163.68±2.27	161.88±2.92	-1.80±0.90^{b}	160.69±0.59	162.04±0.86	1.35±1.02^{a}
L3	166.67±4.39	165.31±4.60	-1.36±0.55^{b}	164.81±1.59	166.06±1.52	1.26±0.93^{a}

[1] ANOVA test was used to identify significant differences ($P<0.05$) between the two experimental groups, where values in the row with the same letter do not differ significantly. [2] Difference (final assessment - initial assessment) of angles at the thoracolumbar, was calculated for each axial segment marker. Source: Authors (2022).

4. Discussion

In athletic horses, to keep them healthy, it is essential to search for body symmetry and good posture of the spine (Van Weeren et al., 2010; Higgins, 2015). Since the horse is a quadruped animal, the thoracolumbar region is aligned horizontally, with a position of relative extension, described as lordotic. However, if lordosis increases, this can contribute to the appearance of bone lesions as well as soft tissue injuries (Cocq et al., 2004). Spinal problems have been associated with dysfunctional changes in head/neck posture. These changes can also affect lordosis of the thoracolumbar region (ventral displacement of the spine) and consequently interfere with flexion of the spine. Horses with lordotic thoracolumbar region posture have been related to the presence of pain and pathologies, such as kissing spine (Taylor et al., 2019).

Thus, in the present trial, the dynamic mobilization exercises produced a dorsal displacement of the horses' thoracolumbar spine by 6.8 cm, as well as increased the degree of flexion of this segment by 15.54°. This kinematics of the axial segment is in agreement with the functional theory of the equine spine called "bow and chord" as well as supporting the primary hypothesis of the study. In a previous study, Zimmerman at al., (2012), reported the importance of spinal flexion movements, as this region is commonly associated with pain and poorer performance in equines. In this study spinal flexion was measured by the maximum reduction in thoracolumbar depth and the maximum increase in thoracolumbar angle demonstrating flexion (Berner et al., 2012; Rhodin et al., 2005; Van Weeren et al., 2010), similarly to the methodology adopted in the current trial. Thus, the thoracolumbar markers used were consistent to demonstrate flexion as well as dorsal displacement of the spine.

Unlike that observed by Taylor et al., (2019), after a single session of spinal mobilization, for all thoracolumbar markers. The researchers justified this inconsistency for methodological reasons, such as error in marker fixation, bony anomalies of the anatomical points used (Stubbs et al., 2006), as well as for pathological reasons (Vanderbroek et al., 2016), unfavorable conformation or subclinical discomfort, caused by external factors such as rider asymmetry or poor saddle fit (Denoix, 1998).

The good results of the current research were due to the head/neck positions required by the dynamic mobilization exercises recruited the deep muscles responsible for the vertebral posture (Clayton, 2004). According to Oliveira et al., (2014), the head and neck position that the horse assumes has great interference in the mobilization of the thoracolumbar segment. These researchers found that horses trained with the Pessoa rein, in which the head/neck position was assumed low (neck below the withers), promoted greater flexion of the dorsolumbar region and thus favoring hypertrophy of the Musculus Multifidus (MM), an important deep and postural muscle.

The MM is a deep muscle that lies medial to the Longissimus Dorsi (LD), is not accessible by external visual assessment and originates from the transverse processes of the cervical, thoracic, lumbar and sacral vertebrae (Stubbs et al., 2006). Functionally, this muscle is important for protection against the production of abnormal rotation and for the distribution of force throughout the spine, generated by the pelvic muscles (McGowan et al., 2007). It also produces segmental stabilization and control of the spine in horses, allowing intervertebral movement near the neutral position during the animal's displacement (Haussler et al., 2007; Stubbs et al., 2006).

However, other mechanisms are involved with dysfunction in the thoracolumbar region of horses that include, weakness in the abdominal muscles, hypertonicity in the epaxial muscles, claudication of the appendicular segment, as well as bone pathology (Haussler, 2010). Thus, strengthening the core muscles is of paramount importance in athletic horses to stabilize and control undesirable movements to the intervertebral segment (Stubbs, et al., 2011). The dynamic mobilization exercises in the current research, have been shown to recruit the epaxial, abdominal, and sublumbar muscles (Oliveira et. al., 2019). Thus, the longitudinal and lateral flexion movements, which constitute the dynamic mobilization exercises, increased tension in the spine and instability in the intervertebral segment, which culminated in dorsal displacement (Table 1) and greater degree of flexion of the thoracolumbar region (Table 2) after four months of exercises. Thus, this increase in tension occurred as a result of the increased action of the abdominal muscles, which were recruited as a consequence of the imbalance generated by the dynamic lateral mobilization exercises, as well as by the activation of the epaxial muscles, which intensified the flexion and dorsal displacement of the spine. This explanation is based on the numerous studies that have identified hypertrophy of the epaxial musculature, Musculus multifidus, in horses submitted to dynamic mobilization exercises (Stubbs et al., 2011, Tabor, 2015, Oliveira et al., 2015, Rodrigues et. al., 2021).

The presence of pain in the thoracolumbar region is often associated with muscle hypertonicity and restriction in range of motion. King et al., (2022), researched the effects of dynamic mobilization exercises associated with the use of electromagnetic energy and found significant improvement in the mobility and flexibility of the animals' spine. The researchers found that the horses developed increased thoracolumbar flexion, in agreement with the results found in the current trial. Additionally, they concluded that maintaining thoracolumbar flexibility, as well as symmetry in lateral flexions, allows the horse to better control movement efficiently and effectively during sport-specific tasks. Similarly, in a previous study by Stubbs et al., (2011), they found that dynamic mobilization exercises, such as those performed in the present study, have been shown to stimulate hypertrophy and increased symmetry between the right and left sides of the sectional area of the MM in sedentary, equine therapy horses (Oliveira et. al., 2015) and in racehorses (Tabor, 2015). Hypertrophy and symmetry of the LL are important for a flexible spine, in promoting pain-free movement of the spine, greater neuromotor control, and efficiently improving muscle strength gain.

Another explanation for the result found in the present study is based on the fact that manual therapy techniques, such as dynamic mobilizations, can stimulate peripheral joint receptors and also the central nervous system pattern, which causes reflex muscle relaxation, altering motor function and thus improving spinal flexibility (Cassidy et al. 1992; Schmid et al.

2008). However, the exact mechanism of action for the improvement in thoracolumbar flexion is unknown, so further evaluation of the individual components of dynamic mobilization exercises is warranted to better understand how spinal flexion is created.

5. Conclusion

Dynamic mobilization exercises consistently produce flexion of the axial segment, making them a potential tool to improve range of motion and function of the thoracolumbar spine in horses.

Thus, pursuing this line of research to study the effect of dynamic mobilization associated with neuro-reflexive exercises on the kinematics of the spine becomes important for understanding the factors responsible for generating and increasing flexion in the thoracolumbar spine of horses.

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