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CASE STUDY

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DIGITAL ANALYSIS OF THE DOG'S GAIT AS A TOOL FOR EARLY DIAGNOSIS OF LOCOMOTOR DYSFUNCTION – CASE STUDY

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ABSTRACT

The use of digital kinematic analysis in veterinary medicine provides great opportunities to diagnose lameness in dogs. The aim of the study was to determine the lateralization of the dog's gait and to create a gait model for a given individual at walk and trot. The material used for the study was a boxer bitch. The study was carried out on a dogPACER treadmill at feed speeds allowing the dog to move at walk and trot. The analysis performed in the Noraxon MyoVideo program included the length of the step and angulation in the joints in the three phases of movement. A comparative analysis of the angle values in the joints in both gait types indicates statistically significantly larger angulation ($P \leq 0.05$) in the joints of the pelvic and thoracic limbs and a reflection of these changes in the distance between the steps taken. Deviations are most often visible for the left hip, knee and ankle joints and intensify when the gait rate increases in the initial phase of limb transfer. In addition to differences for the pelvic limbs, significant differences were found for angulation in the shoulder and elbow joints. The results indicate the advantages of kinematic analysis as a tool for early diagnosis of changes in the locomotor apparatus, which allows the implementation of appropriate therapy aimed at restoring the normal motor functions of the body.

Key words: dog, physiotherapy, kinematic analysis, motion

INTRODUCTION

The first attempts to assess the movement of four-legged animals are dated to the 19th century [Gillette and Zebas 1999], when photographic material was mainly used for analysis [DeCamp 1997]. Currently, the most popular method of assessing animals with locomotor problems is the subjective qualification of a veterinarian or animal physiotherapist based on a preliminary visual assessment. However, even for a trained eye, lameness may often not be visible and movement disorders may be difficult to detect [Carr and Dycus 2014].

Progress in the development of objective methods, such as digital kinematic analysis of dog movement, came with the development of computer technologies in the 1980s, giving huge diagnostic possibilities in veterinary orthopedics and veterinary neurology [Naito et al. 1990, DeCamp 1997]. Numerous studies conducted on dogs confirm the validity of using this type of analysis to detect dysfunctions within the locomotor apparatus and to evaluate after surgery and rehabilitation [Au et al. 2010].

Quantitative (kinematic) analysis, as a systematic measurement of the characteristics of locomotion, allows a better understanding of the relationship between elements of the locomotor apparatus, and thus the way dogs move, accurately identifying the characteristic features of a given individual's motion model, quantifying the geometric and time relationships of body segments relative to each other and to space [Clayton 1996, Sandberg et al. 2020]. Such analyzes are carried out on the basis of data collected during filming of an animal covered with markers emitting reflection after exposure to infrared or visible light [Anderson and Mann 1994]. They are placed in characteristic anatomical points, usually they are points of joint rotation, significant bone protuberances or areas

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of the body determined on the basis of precise calculations, performing important movements for the study [Allen et al. 1994, McLaughlin 2001]. The most frequently presented are speed parameters, angular accelerations and movement patterns of limbs during their activities, such as time of individual phases and length of steps as well as linear speed.

The results of such analysis, as well as their interpretation and comparison of parameters with the data contained in specialist literature describing dogs, give the opportunity to accurately determine the manner in which a given individual moves. The precision of the method makes it possible to determine the exact location of changes before developing problems are visible to the naked eye [Agostinho et al. 2011]. The method is extremely sensitive, which results in the maximum reduction of the diagnosis time and, therefore, recovery. This is related to the economic aspect, almost as important as animal welfare, especially for working and sporting dogs.

To properly analyze a dog's motion, you need to know the anatomical relationships and biomechanics of individual gaits. Most often, dogs moving on the treadmill at walk and trot are used for research. These are gaits that allow you to thoroughly analyze possible deviations between lateral parameters. The difference between them is primarily to increase the vertical movements of the body and increase the angulation in the joints of the limbs during the transfer phase. These changes reach up to 30° for the hip joint and up to 60° for the knee, which allows better to observe deviations between the left and right side [Nunamaker and Blauner 1985]. The relationships of individual elements of dog biomechanics affect the final effect shaping the individual's gait model. This model varies depending on the breed, body type, but also on the type of work performed by the dog [Zink and Van Dyke 2013]. Regardless of the body type, individual gaits are characterized by specific elements. The walk is a four-beat, asymmetrical gait, where each limb is placed in turn. The dog alternates between two and three limbs. The support phase with three limbs is characteristic for walking and distinguishes it from other gait types [Carr and Dycus 2014]. The pelvic limb should move first, following the pectoral limb on the same side and falling to the ground in the place where the pectoral limb moves. It should be remembered that this pattern may change a little depending on the body type – especially small dogs show high variability. Unlike the walk, the trot is a symmetrical, two-beat gait in which the suspension phase should occur. The dog is trotting at the same time with diagonal thoracic and pelvic limbs. For most breeds and body types, each pair of limbs touches the ground and stands out at the same time. After each bounce of the next pair of limbs, before the next pair goes into the support phase, there is a suspension moment when none of the limbs comes into contact with the ground [Nunamaker and Blauner 1985, Carr and Dycus 2014, Zink and Canapp 2015]. The suspension phase has been minimized or completely disappeared due to the anatomical structure of some breeds and body types – among others in molossus dog breed [Nunamaker and Blauner 1985, Zink and Van Dyke 2013, Zink and Canapp 2015].

This study is a pilot study and it should be carry out similar experiments on different breeds of dogs, which would allow for a thorough understanding of their gait pattern, and thus use of the collected data in the process of early diagnosis of functional disorders of the musculoskeletal system.

The aim of the study was to determine the model of dog's movement at the walk and trot (angular ranges and distance between the put limbs) using kinematic analysis. Determining the relationship between angulation and the distance of the limbs put leads to the determination of deviations between the sides, and consequently to indicate possible changes within the movement apparatus of the examined individual. Kinematic analysis as a non-invasive method of diagnosing lameness in dogs can be widely used in the prevention of working and sporting dogs, in which the problem is detected as soon as possible, gives the opportunity to maximally reduce the time of treatment and recovery. This is an important aspect, especially for animal owners whose exclusion from training has serious economic consequences.

MATERIAL AND METHODS

Subject of research

A female of the boxer breed type, 6 years old, was used for the study. Spine x-ray showed changes indicating the initial stage of spondylosis in the thoracic and lumbosacral segment. On the eve of the test, the animal was clinically examined by a veterinarian and a qualified animal physiotherapist to exclude visible deviations in movement and to eliminate possible contraindications to treadmill training (kinesitherapy). In orthopedic and neurological terms, the dog showed no abnormalities. Before the study, animal was weighed (24 kg) and measured (height at withers: 60 cm; length from the most cranial point of the main body to ischial tuberosity: 64 cm).

Course of the study

The study was performed in 5 sessions of 30 minutes. Before proceeding to the main part of the experiment, the dog was used to walking on the treadmill. Each time the training was preceded by the author's warm-up protocol in the same order of exercises. The warm-up included the following exercises: walking at the walk and then at the trot (not less than 10 minutes and not more than 15 minutes, of which the initial phase of the walk was not less than 5 minutes), active stretching, lasting 3 to 5 minutes (walking around the circle, slalom, tug-of-war, giving a paw, "bow"'). After warming up, markers were attached to the dog's body based on characteristic bone points (2/3 of the length of the scapula crest; 2. area of the greater tubercle of the humerus; 3. area of the lateral epicondyle of the humerus; 4. area of the styloid process of the ulna) corresponding to the axis of rotation of the goniometer [Jaegger et al. 2002].

In order to analyze the obtained results, a scheme for determining the sides of the animal based on the median plane was adopted (A, B – left side, A′, B′ – right side), where the thoracic limbs were marked as A, A′, and the pelvic limbs B, B′.

In the study, the dog moved on a horizontal treadmill dogPACER model LF-3.1, whose dimensions are adapted to achieve trot movement (for dogs up to 80 kg), thanks to the use of a tape measuring 180×42 cm. The feed speed of the treadmill belt was adjusted to the speed of movement of the examined individual in walk (3.5 km · h^{-1}) and trot (7 km · h^{-1}). The video materials used for the analysis were recorded at a right angle to the object with a Logitech 920Pro camera. The image quality in Full HD 1080p, at 30 frames per second allowed to record the material enabling its correct analysis using the Noraxon MyoVideo software (USA, Quincy). The Noraxon MyoVideo software provides the ability to track markers based on appropriate algorithms, which helps in assessing the correctness of movement. The program analyzed film fragments, selected in terms of repeated dog movement, without lateral head movements and gait pace changes.

Angle of joint movement range was measured using a digital goniometer and included shoulder, elbow, wrist, hip, knee and ankle joints. The measurements were made in three phases of limb position at the walk and trot, according to the diagram presented by Agosthino et al. [2011]. In addition, the distance between the limbs in the support phase was measured (Fig. 1).

Statistical analysis. The analysis was carried out for two gait types (walk and trot) in the scope of angle and distance measurements between limbs, comparing the left side to the right side. All angle measurements were further divided into ranges in three consecutive phases of limb movement (beginning of the support phase, beginning of the transfer phase and culmination of the transfer phase).

The results obtained were divided into two parts. The first part presents parameters of angle measurements for pelvic and thoracic limbs at the walk and trot, as well as occurring lateralizations. The second part concerns the analysis of the length of the distance between the limbs during the support phase (measured diagonally).

Statistica 13.1 PL was used to perform statistical verification of results, using descriptive statistics and tests verifying the statistical significance of differences. The analysis used dependent sample T-Test (Welch's T-Test in the absence of sample compatibility). Statistical tests were performed for the significance level $P \leq 0.05$.

RESULTS

A comparative analysis of the angle values in the joints, within the pelvic limbs (left vs right) for the beginning of the support phase (Table 1) indicates a statistically significant greater angulation ($P \leq 0.05$) in the hip and ankle joint of the left limb at the trot and the hip joint at the walk. In the thoracic limb, statistically significant ($P \leq 0.05$) greater angulation was found in the elbow joint of the left limb. Other angulation values did not statistically differ.

The analysis carried out in the initial phase of transmission indicates the occurrence of statistically significant differences ($P \leq 0.05$) between mean values, both for pelvic limbs and thoracic limbs on the left and right side (Table 2). The results for the analyzed joints at the beginning of the trot transfer phase are significantly higher in all the joints of the left pelvic and thoracic limb, and in the hip and shoulder joint of the right limb. Other angle values did not differ statistically.

The obtained results for the pelvic limbs in the culmination of the trot transfer phase indicate the occurrence of statistically significant differences ($P \leq 0.05$) only for the knee joint (Table 3). In the case of walk, statistically sig-

Fig. 1. Angle measurement in the pelvic joints at the trot: at the beginning of the support phase (A), the beginning of the transfer phase (B) and the culmination of the transfer phase (C) (own material)

Table 1. Mean (x̄), standard deviation (SD) as well as minimum (Min) and maximum values (Max) for angles (°) in the pelvic and thoracic joints (left and right) at the walk and trot during the initial support phase

Limb		Joint	Walk				Trot			
			x̄	SD	Min	Max	x̄	SD	Min	Max
Pelvic	left	hip	100.5*	5.8	88	108	95.3*	1.4	92	98
		knee	134.3	6.2	122	147	129.9	4.6	118	138
		ankle	136.0	5.5	127	148	133.5*	3.5	126	138
	right	hip	95.7*	2.4	91	100	91.6*	2.9	88	98
		knee	132.1	4.2	125	142	129.5	3.4	125	136
		ankle	134.8	4.5	129	143	130.4*	3.6	124	139
Thoracic	left	shoulder	128.8	4.0	119	133	127.7	4.1	120	136
		elbow	130.7*	3.7	123	139	128.1	7.2	113	139
		wrist	193.9	5.5	184	201	194.3	11.6	160	210
	right	shoulder	128.7	6.1	116	136	126.1	8.1	106	136
		elbow	122.6*	8.0	109	137	126.4	8.3	109	142
		wrist	192.6	7.0	182	206	198.4	8.2	180	209

* – differences in columns between the left and right limb for a given joints are statistically significant ($P \leq 0.05$).

Table 2. Mean (x̄), standard deviation (SD) as well as minimum (Min) and maximum values (Max) for angles (°) in the pelvic and thoracic joints (left and right) at the walk and trot during initial transmission phase

Limb		Joint	Walk				Trot			
			x̄	SD	Min	Max	x̄	SD	Min	Max
Pelvic	left	hip	137.3*	5.3	121	144	128.1*	4.4	118	128.1
		knee	127.0	5.1	116	134	124.4*	4.4	114	124.4
		ankle	152.7	4.4	147	163	146.3*	3.8	141	146.3
	right	hip	138.6*	8.1	128	154	124.1*	5.2	117	124.1
		knee	129.3	4.7	123	142	118.7*	4.4	109	118.7
		ankle	152.7	4.3	142	159	142,1*	4.8	137	142.1
Thoracic	left	shoulder	107.7*	3.4	103	115	107.7*	2.3	103	107.7
		elbow	130.5	4.5	121	137	124.7*	3,1	121	124.7
		wrist	190.6	5.8	178	200	184.3*	7.4	170	184.3
	right	shoulder	111.7*	4.8	105	122	102.5*	2.6	97	102.5
		elbow	130.5	7.4	112	139	121.1*	4.3	115	121.1
		wrist	186.3	10.5	167	207	173.3*	6.1	162	173.3

* – differences in columns between the left and right limb for a given joints are statistically significant ($P \leq 0.05$).

nificant differences were not found for any of the pelvic joints. Within the thoracic limbs, statistically significant differences ($P \leq 0.05$) occur in the case of the elbow joint in both gait types and the wrist joint at the walk.

The results of the range of motion affect the results of measuring the stride length. Despite the compensations occurring on the left side (pelvic limb), you can see differences in the stride length. The stride length of the shoulder limb relative to the pelvic limb is significantly greater on the left than on the right ($P \leq 0.05$). In Table 4 and Figure 2, measurements of the laterally placed limbs at the walk are presented, while in Table 5 the stride length measured diagonally at the walk and trot. Analyzing the stride length in both gaits tested, statistically significant differences ($P \leq 0.05$) were obtained only for walking.

Table 5 and Figure 3 present the results of measuring the limbs placed diagonally. Statistically significant differences ($P \leq 0.05$) were found for short diagonals, where these values are greater on the right front and left rear sides. Analysis of long diagonals at the trot showed no statistically significant differences.

DISCUSSION

The results obtained in our research testify to the disturbance of angles in the joints of both the thoracic and

Table 3. Mean (x̄), standard deviation (SD) as well as minimum (Min) and maximum values (Max) for angles (°) in the pelvic and thoracic joints (left and right) at the walk and trot during culmination of transmission phase

Limb		Joint	Walk				Trot			
			x̄	SD	Min	Max	x̄	SD	Min	Max
Pelvic	left	hip	103.6	6.4	90	115	94.1	3.5	86	94.1
		knee	98.3	6.2	86	110	72.5*	3.5	65	72.5
		ankle	114.5	4.7	106	123	93.8	4.8	88	93.8
	right	hip	101.3	6.1	91	112	92.9	3.8	87	92.9
		knee	96.5	4.0	90	103	67.7*	2.5	65	67.7
		ankle	116.5	4.6	108	122	92.1	2.8	88	92.1
Thoracic	left	shoulder	104.7	4.1	97	113	101.1	5.4	90	101.1
		elbow	84.1*	2.6	80	91	75.5*	6.1	70	75.5
		wrist	101.3*	4.3	93	107	87.1	6.5	75	87.1
	right	shoulder	106.3	5.0	96	116	101.9	3.7	95	101.9
		elbow	88.7*	6.9	76	101	81.3*	5.3	70	81.3
		wrist	93.9*	5.6	84	106	84.1	8.8	66	84.1

* – differences in columns between the left and right limb for a given joints are statistically significant ($P \leq 0.05$).

Table 4. Distances between laterally placed limbs on the right and left at the walk in the support phase

Limb	Side	x̄	SD	Min	Max
Support phases	left (A–B)	51.5*	2.7	48	59
	right (A\`–B\`)	49.7*	2.3	45	54

* – statistically significant differences ($P \leq 0.05$).

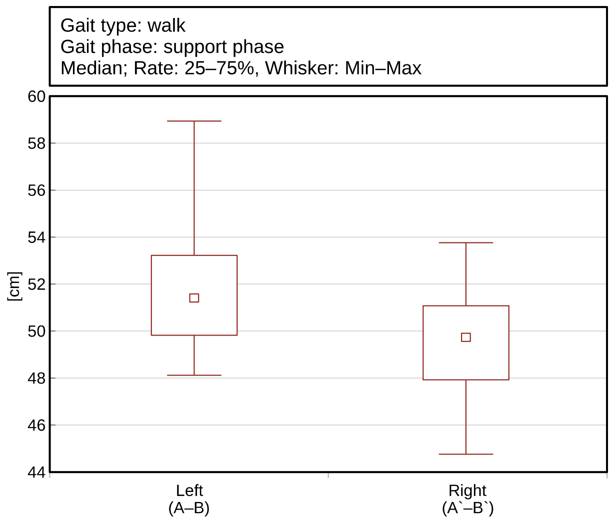

Fig. 2. Distance (cm) between laterally placed limbs on the left and right side at the walk during the support phase

Table 5. Distances between diagonally placed limbs at walk and trot at the initial support phase

Gait type	Motion phase	Side	x̄	SD	Min	Max
Walk	support phases – short diagonal	left (A`–B)	20.4*	3.2	15	27
		right (A–B`)	18.5*	1.6	16	21
	support phases – long diagonal	left (A`–B)	79.4	1.9	75	82
		right (A–B`)	80.3	3.4	72	83
Trot	support phase	left (A`–B)	48.2	1.3	46	51
		right (A–B`)	47.4	2.6	43	52

* – statistically significant differences ($P \leq 0.05$).

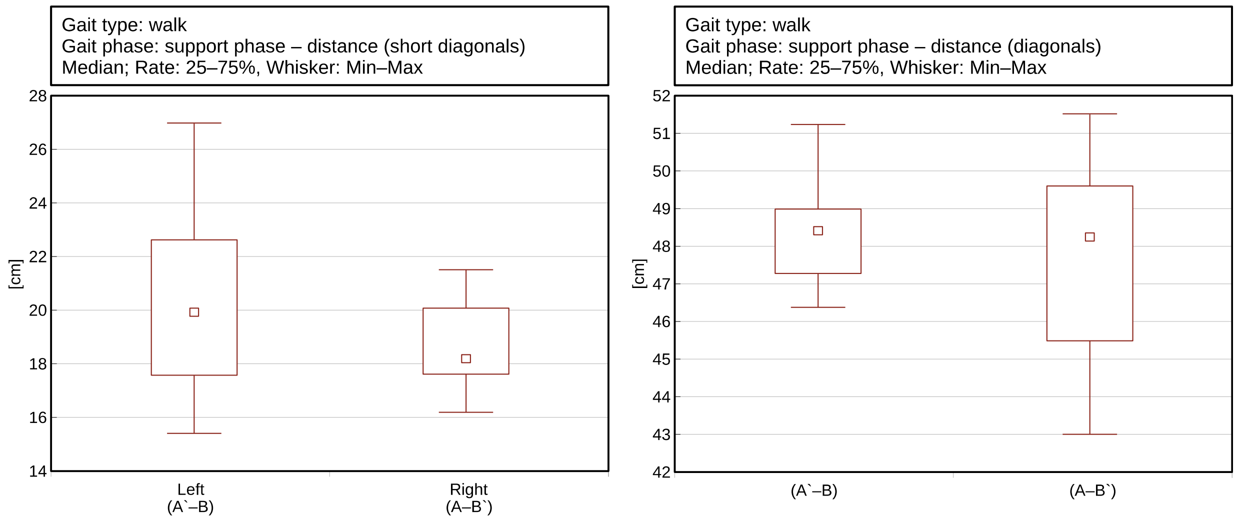

Fig. 3. Distance (short diagonals) between diagonally placed limbs in the support phase for the walk (left) and limbs placed diagonally for the trot (right)

pelvic extremities. Changes in angulation in motion are also associated with a change in the distance of the limbs placed diagonally and laterally. They indicate deviations from the correct symmetry, which was analyzed by many researchers [Schaefer et al. 1998, Conzemius et al. 2005, Gillette and Angle 2008]. Deviations in measurements between the right and left limb may suggest pathological changes in the area of the left hip joint. This confirms the reduced joint mobility (greater flexion angle) especially during the support phase at the trot. It may be associated with neurological or orthopedic problems [Naito et al. 1990]. Faster gait, resulting in higher loads, increases the angle differences for the knee and ankle joints, as well as the joints of the thoracic limbs – especially the shoulder joint. Changes in angulation reduce the distance between the limbs on the side with reduced mobility, which results in a shorter stride. Angular ranges of the joints of the thoracic limbs may be the answer to the anomalies of pelvic limb movement on the left side. This is due to the compensation of reduced mobility of the hip in order to achieve a similar stride length on both sides. These deviations are to maintain maximum symmetry of gait by aligning the stride length on the left with respect to the right. Abdelhadi [2012] study deals with the mechanism of compensation occurring in the musculoskeletal system, and the obtained results confirm the results of our research. It should also be remembered that changes in the manner of placing limbs may vary depending on the angle of inclination and variability of the ground [Holler et al. 2010]. All pathological changes occurring within the locomotor apparatus affect the formation of changes in the motion model of a given individual [Naito et al. 1990].

Specialized literature dealing with changes in the pattern of dog movement as a consequence of trauma or orthopedic or neurological problems confirms significant deviations from the symmetry of angular ranges and the distance between the limbs on the side of the dysfunction, on which these values were usually reduced [Poy et al. 2000, Torres 2010, Boddeker et al. 2012, Torres et al. 2013], which was also shown in our own research.

The video analysis method used to evaluate the movement pattern can be used for early diagnosis of lameness in dogs. Although the way of movement is characteristic for the breed, body type or individual predispositions [DeCamp et al. 1993, Allen et al. 1994, Clements et al. 2005, Kano et al. 2016], numerous sources present the assumptions of the general model of musculoskeletal function for a given species and despite significant variability within it, it does not affect however significant deviations from the model of angulation of individual joints during movement [Hottinger et al. 1996, Bertram et al. 2000, Breur et al. 2014]. This is indicated by slight differences in the angular ranges obtained in the study and available in specialist literature describing the features of the labrador and rottweiler movement apparatus [Agostinho et al. 2011, Silva et al. 2014]. The differences between the results obtained from the analysis of dog movement in our research and those described in Labradors and Rottweilers [Agostinho et al. 2011, Silva et al. 2014] are small, and the overall model of movement in the joints is similar. Schaefer et al. [1998] in their research show that each joint has a characteristic flexion and extension pattern and that no variables were detected in the distance between the left and right side, suggesting symmetry of gait. In view of the above, it can be assumed that the occurrence of slight deviations is the result of individual characteristics, level of training, anatomical features or pathological changes within the locomotor system.

The method of kinematic analysis presented in the author's work makes it possible to perform measurements in a simple and non-invasive way (range of the angle of joint movement and length of stride), thanks to which it is possible to determine the model of the animal's gait with simultaneous precise indication of the location of any changes within the locomotor apparatus. It is a method sensitive to discrete changes in the analyzed parameters, i.e. changes in the animal's movement model, in which there are no visible problems in the functioning of the locomotor system. This is particularly important in the case of working and sporting dogs, where early diagnosis can protect the animal from a serious injury eliminating them from training. The use of kinematic analysis in the clinical assessment of gait regularity will make it possible to identify changes before they become visible.

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CYFROWA ANALIZA CHODU PSA JAKO NARZĘDZIE WCZESNEJ DIAGNOSTYKI ZABURZEŃ APARATU RUCHU

STRESZCZENIE

Zastosowanie cyfrowej analizy kinematycznej w weterynarii daje ogromne możliwości diagnozowania kulawizn u psów. Celem badań było określenie lateralizacji chodu psa oraz stworzenie modelu chodu dla danego osobnika w stępie i kłusie. Materiałem użytym do badań była suka rasy bokser. Badanie przeprowadzono na bieżni dogPACER przy prędkościach posuwu umożliwiających psu poruszanie się w stępie i kłusie. Analiza przeprowadzona w programie Noraxon MyoVideo obejmowała określenie długości kroku i kątowania w największych stawach kończyn w trzech fazach ruchu. Analiza porównawcza wartości kątów w stawach w obu typach chodu wskazuje na istotnie statystycznie większe wartości zagięcia ($P \leq 0{,}05$) w stawach kończyny miednicznej i piersiowej oraz odzwierciedlenie tych zmian w odległości między wykonywanymi krokami. Odchylenia są najczęściej widoczne dla lewego stawu biodrowego, kolanowego i skokowego i nasilają się wraz ze wzrostem tempa chodu w początkowej fazie przeniesienia kończyny. Oprócz różnic w katowaniu kończyn miednicznych, istotne różnice stwierdzono również dla kątowania w stawach barkowych i łokciowych. Uzyskane wyniki wskazują na zalety analizy kinematycznej jako narzędzia wczesnego diagnozowania zmian w aparacie ruchu, co pozwala na wdrożenie odpowiedniej terapii mającej na celu przywrócenie prawidłowych funkcji ruchowych organizmu.

Słowa kluczowe: pies, fizjoterapia, analiza kinematyczna, ruch

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