Hind limb kinematics during therapeutic exercises in dogs with osteoarthritis of the hip joints

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Objective—To assess joint kinematics in dogs with osteoarthritis of the hip joints during walking up an incline or down a decline and over low obstacles and to compare findings with data for nonlame dogs.

Animals—10 dogs with osteoarthritis of the hip joints (mean ± SD age, 6.95 ± 3.17 years; mean body weight, 34.33 ± 13.58 kg) and 8 nonlame dogs (3.4 ± 2.0 years; 23.6 ± 4.6 kg).

Procedures—Reflective markers located on the limbs and high-speed cameras were used to record joint kinematics during walking up an incline or down a decline and over low obstacles. Maximal flexion, extension, and range of motion of the hip joints were calculated.

Results—Osteoarthritis of the hip joints reduced extension of both hip joints and flexion of the contralateral hind limb, compared with flexion of the lame hind limb, during walking down a decline. Walking up an incline resulted in decreased extension of the stifle joint in both hind limbs of osteoarthritic dogs; extension was significantly decreased for the lame hind limb. During walking over low obstacles, maximal flexion of the stifle joint was increased significantly for the contralateral hind limb. Maximal flexion was increased in both tarsal joints.

Conclusions and Clinical Relevance—Osteoarthritis of the hip joints led to complex changes in the gait of dogs, which involved more joints than the affected hip joint alone. Each exercise had specific effects on joint kinematics that must be considered when planning a rehabilitation program. (*Am J Vet Res* 2012;73:1371–1376)

Hip dysplasia and associated osteoarthritis are among the most common orthopedic disorders in dogs. During the past few decades, a variety of management and breeding strategies have been developed to decrease the incidence of hip dysplasia within the canine population. Focus has been put on preventive management, including restricted exercise during the growing period and limited food consumption.[1,2] Surgical interventions for the management and treatment of hip dysplasia include juvenile pubic symphysiodesis (electrocauterization of the physeal cartilage of the pubic symphysis), double and triple pelvic osteotomy, and total hip endoprothesis.[1,3] In addition to these surgical interventions, conservative medical management includes administration of anti-inflammatory pain-relieving drugs,[4] weight management,[5,6] and physical therapy.[7,8] Physical therapeutic approaches include modalities such as electrotherapy[8] for pain management and therapeutic exercises to improve muscle mass, strength, ROM, and function of the joints.[8] However, even though physical therapy for domestic animals is a growing field, a limited number of studies have been conducted to address the effectiveness of these methods. Furthermore, particularly with regard to therapeutic exercises, there is limited information on the biomechanics of joints and muscles.

Gait analysis currently is considered the criterion-referenced standard for obtaining information on the influence of orthopedic disorders on joint mechanics and investigating the effectiveness of treatment modalities. Biomechanics research has focused primarily on walking on horizontal surfaces,[9–11] and there is a lack

Abbreviations

GRF	Ground reaction force
IFz	Vertical impulse
PFz	Peak vertical force
ROM	Range of motion
SI	Symmetry index

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of studies conducted to investigate the effects of special movements, such as climbing stairs, walking over obstacles, and walking down a decline or up an incline. In a few studies,[12–14] climbing stairs was investigated. Investigators in another study[15] evaluated the effect of incline, decline, and obstacle exercises in healthy dogs. They found that obstacle exercise significantly increased flexion of the elbow, carpal, stifle, and tarsal joints and extension of the carpal and stifle joints.[15] Walking up an incline increased flexion of the hip joints and decreased flexion of the stifle joints, and walking down a decline decreased flexion of the hip joints. Those authors concluded that each exercise has specific value for improving restricted joint movement. Even though that study[15] illuminated some of the effects of special movements on joint mechanics, it did not involve evaluations of animals with orthopedic disorders. This is unfortunate because a deeper insight on the effect of special movements on joint kinematics would help increase understanding of the consequences of joint diseases and the requirements of rehabilitation.

The objective of the study reported here was to investigate the kinematics of joints during walking up an incline or down a decline and over low obstacles in dogs with osteoarthritis of the hip joints. We hypothesized that in dogs with osteoarthritis, flexion and extension of the tarsal, stifle, and hip joints would undergo major changes, compared with results for nonlame dogs.

Materials and Methods

Dogs—Data from 8 nonlame dogs with a mean ± SD age of 3.4 ± 2.0 years and body weight of 23.6 ± 4.6 kg were obtained from a previous report.[15] These dogs included 1 Labrador Retriever, 3 Golden Retrievers, 1 Large Münsterländer, 1 Australian Shepherd Dog, 1 Border Collie, and 1 Nova Scotia Duck Tolling Retriever. All dogs had been subjected to thorough orthopedic[16] and clinical and neurologic[17] examinations.

Ten dogs with clinically and radiologically evident osteoarthritis of the hip joints were prospectively enrolled in the study. Mean ± SD age was 6.95 ± 3.17 years, and mean body weight was 34.33 ± 13.58 kg. Four dogs were females, and 6 were males. There were 3 Golden Retrievers, 2 Labrador Retrievers, 1 Small Müensterländer, and 4 mixed-breed dogs (the mixed-breed dogs had a body type comparable to that of the 6 purebred dogs). All dogs were subjected to thorough orthopedic[16] and clinical and neurologic[17] examinations. Degree of lameness[18] and signs of pain were scored on a 5-point scale.[18] The diagnosis of osteoarthritis was radiologically confirmed. In all 10 dogs, there was bilateral radiographic evidence of osteoarthritis of the hip joints. Dogs were included only if there was detectable lameness and signs of pain were evident during palpation of the hip joints. Dogs in which joints other than the hip joints were affected with osteoarthritis were excluded from the study.

Informed consent was obtained from the owner of each dog. The study was approved by an institutional ethics committee.

GRF measurements—To substantiate clinical findings, exclude subclinical lameness in the 8 nonlame dogs, and confirm lameness in the 10 dogs with osteoarthritis of the hip joints, kinetic measurements were obtained by use of a treadmill that was specifically developed for dogs. Measurement procedures have been described in detail.[15] Data for all 10 dogs with osteoarthritis of the hip joints were obtained over a 6-month period, and the equipment, measurement procedures, software, and investigators were the same for all measurements.

The PFz and IFz were evaluated and expressed as a percentage of body weight. In the dogs with osteoarthritis of the hip joints, the limb with the lower GRF was considered the lame limb. The left hind limb in the nonlame dogs was used as the comparison for the lame limb and the right hind limb as comparison for the contralateral limb.

An SI for each measured variable was calculated with the following equations:

$$SIPFz = ([PFz_L - PFz_R]/[PFz_L + PFz_R]) \times 100$$

and

$$SIIFz = ([IFz_L - PFz_R]/[IFz_L + IFz_R]) \times 100$$

where SIPFz and SIIFz are the percentage difference in weight distribution between the left and right limbs of each dog for the calculated variable PFz or IFz, respectively; PFz_L and PFz_R are the PFz values for the left limb and right limb, respectively; and IFz_L and IFz_R are the IFz values for the left limb and right limb, respectively.

Kinematic measurements—The equipment and measurement procedures have been described in detail[15] and were identical in all 10 dogs with osteoarthritis of the hip joints. Reflective markers were affixed to the skin of the dogs overlying the cranial dorsal iliac spine, greater trochanter of the femur, stifle joint between the lateral epicondylus of the femur and head of the fibulae, lateral malleolus, and distal aspect of the fifth metatarsal bone of the hind limb. To assess walking velocity, an additional marker on the fifth metacarpal bone of the left forelimb was used. Markers were affixed only on the left limbs of nonlame dogs and on both hind limbs of the dogs with osteoarthritis of the hip joints. Assessments of each dog during walking up an incline, down a decline, and over low obstacles were performed. The slope of the incline and decline was 11%. Height of the 5 obstacles was adjusted to the height of the carpal joint of each respective dog, and distance between each obstacle was determined on the basis of the distance between the forelimb and hind limb of each dog.

Dogs were allowed to become acclimated to the measurement procedure. Then, each dog performed each exercise at least 6 times. Mean velocity of the dogs was assessed by use of the marker on the fifth metacarpal bone of the left forelimb; mean ± SD velocity was 1.0 ± 0.47 m/s during walking over low obstacles, 1.06 ± 0.54 m/s during walking up the incline, and 1.14 ± 0.53 m/s during walking down the decline.

Data recording and evaluation were performed with a motion-analysis program[a] for angle analysis, and a sequencing program[b,c] was used for the calculation of motion cycles. Sequencing of motion cycles was conducted on the basis of the horizontal velocity of the marker on the distal aspect of the fifth metacarpal bone, and motion cycles were separated by detecting the zero positions of the velocity (1 motion cycle was defined as the interval between the first and third zero positions of the horizontal speed of the marker).

For each dog, 5 motion cycles were used to calculate the 3-D angles. An overall mean of each motion cycle was calculated and subtracted from each time frame to adjust each motion cycle to a neutral position so that we could differentiate flexion and extension. The mean of the 5 motion cycles was calculated for each dog to determine an individual angle-time curve. Variables investigated were the maximal extension and flexion arithmetic angles and the ROM (maximum extension minus maximal flexion). Duration of the swing phase was calculated and expressed as a percentage of the motion cycle. Values for the left hind limb in the nonlame dogs were used for comparison.

Statistical analysis—Data were evaluated via the Kolmogorov-Smirnov test to ensure a normal distribution. All data were normally distributed, and results were reported as mean ± SD.[d] An unpaired Student *t* test was used to detect differences between nonlame and osteoarthritic dogs. To evaluate differences between the lame and contralateral limb in dogs with osteoarthritis of the hip joints, a paired Student *t* test was used. Values of $P < 0.05$ were considered significant.

Results

The orthopedic[16] and clinical and neurologic[17] examination of the 8 nonlame dogs did not reveal any abnormalities. For dogs with osteoarthritis of the hip joints, lameness was rated as 2 of 5 in 8 dogs and 3 of 5 in 2 dogs. Of the 20 hip joints investigated, signs of pain were scored as 1 of 5 in 2 hip joints, 2 of 5 in 9 hip joints, 3 of 5 in 8 hip joints, and 4 of 5 in 1 hip joint.

The kinetic analysis did not reveal a significant difference in mean ± SD values between forelimbs and hind limbs in the nonlame dogs for PFz (left, 42.03 ± 4.49%; right, 41.75 ± 4.07%) or IFz (left, 17.73 ± 4.09%; right, 16.32 ± 3.17%). There were no significant differences between left and right limbs of the nonlame dogs.

In the dogs with osteoarthritis of the hip joints, mean ± SD PFz was significantly ($P = 0.01$) different between the lame limb (41.87 ± 3.23%) and contralateral limb (45.39 ± 2.03%). Mean IFz also was significantly ($P = 0.01$) different between the lame limb (20.47 ± 9.09%) and contralateral limb (22.42 ± 8.62%). There was a significant ($P = 0.02$) difference in PFz between the contralateral limb of dogs with osteoarthritis of the hip joints and the right hind limb of the nonlame dogs. Other variables did not differ significantly between nonlame and osteoarthritic dogs. For the nonlame dogs, mean ± SD SIPFz was 1.79 ± 1.3% and mean SIIFz was 4.2 ± 1.3%. For the dogs with osteoarthritis of the hip joints, mean ± SD SIPFz was 4.11 ± 2.37% and mean SIIFz was 6.03 ± 3.3%. The SIPFz of the dogs with osteoarthritis of the hip joints was significantly ($P = 0.01$) higher than the value in the nonlame dogs.

Walking up the incline resulted in a significant ($P = 0.04$) decrease in extension of the stifle joint in the lame limb of the dogs with osteoarthritis of the hip joint (**Table 1**); these dogs also had a decrease (but it was not significant [$P = 0.07$; statistical power, 50.9%]) in the contralateral limb. This was also evident for ROM, which was significantly ($P = 0.04$) decreased in the lame limb and also decreased (but not significantly [$P = 0.09$; statistical power, 48.9%]) for the contralateral limb. Comparing hip joint kinematics of the lame limb versus the contralateral limb revealed that flexion was reduced significantly ($P = 0.03$) in the contralateral limb. Compared with the mean ± SD duration of the swing phase for the left hind limb of the nonlame dogs (44.22 ± 3.9%), the mean duration in dogs with osteoarthritis of the hip joint was significantly shorter for both the lame limb (38.36 ± 5.4%; $P = 0.02$) and contralateral limb (38.96 ± 5.7%; $P = 0.04$). No significant ($P = 0.64$) differences were detected in duration of the swing phase between the lame limb and contralateral limb of dogs with osteoarthritis of the hip joint.

Walking down the decline affected only hip joint kinematics. Hip joints of the lame limb ($P = 0.04$) and

Table 1—Mean ± SD values for extension, flexion, and ROM of the lame and contralateral tarsal, stifle, and hip joints of 10 dogs with osteoarthritis of the hip joints and 8 nonlame dogs during therapeutic exercises (walking up an incline, down a decline, and over low obstacles).

	Tarsal			Stifle			Hip		
Variable	Nonlame	Lame	Contralateral	Nonlame	Lame	Contralateral	Nonlame	Lame	Contralateral
Up an incline									
Extension	21.92 ± 3.1	18.27 ± 5.6	18.02 ± 5.3	13.05 ± 2.6	10.63 ± 2.0*	10.72 ± 2.4	15.11 ± 3.8	13.21 ± 4.2	13.52 ± 3.3
Flexion	–16.07 ± 1.9	–17.87 ± 3.3	–17.05 ± 3.9	–23.08 ± 2.3	–21.88 ± 1.9	–21.94 ± 2.9	–15.11 ± 3.7	–15.36 ± 4.0	–13.11 ± 2.7†
ROM	38.05 ± 4.0	36.15 ± 7.3	35.08 ± 8.05	35.93 ± 3.7	32.51 ± 2.9*	32.67 ± 3.9	30.3 ± 7.1	28.58 ± 7.9	28.58 ± 7.9
Down a decline									
Extension	15.51 ± 2.5	14.10 ± 3.2	14.71 ± 3.1	19.86 ± 3.5	19.94 ± 4.8	21.52 ± 2.4	13.90 ± 3.6	10.77 ± 2.4*	10.30 ± 2.9*
Flexion	–17.05 ± 4.4	–18.14 ± 3.8	–17.93 ± 4.1	–25.07 ± 3.3	–24.35 ± 3.2	–25.47 ± 2.3	–11.02 ± 3.7	–10.05 ± 1.9	–8.67 ± 2.2†
ROM	32.65 ± 5.7	32.36 ± 2.3	32.54 ± 3.1	44.67 ± 6.1	44.29 ± 6.7	46.99 ± 2.3	24.85 ± 6.0	20.82 ± 3.7	18.98 ± 4.8*
Over low obstacles									
Extension	19.55 ± 1.5	17.59 ± 3.0	17.20 ± 1.7‡	22.52 ± 3.7	22.31 ± 3.6	24.40 ± 1.22	14.15 ± 3.4	12.79 ± 2.4	13.03 ± 2.1
Flexion	–34.67 ± 5.6	–45.50 ± 4.4‡	–43.38 ± 4.0*	–42.98 ± 7.6	–48.63 ± 4.7	–49.44 ± 3.4*	–13.32 ± 3.4	–15.59 ± 3.4	–14.27 ± 3.5
ROM	55.60 ± 7.4	63.10 ± 6.1*	60.59 ± 5.0	65.98 ± 10.1	70.95 ± 8.0	73.85 ± 3.8*	27.27 ± 6.2	28.38 ± 5.3	27.30 ± 5.1

*Within a joint in a row, value differs significantly ($P < 0.05$) from the value for the nonlame dogs. †Within a joint in a row, value differs significantly ($P < 0.05$) from the value for the lame limb in dogs with osteoarthritis. ‡Within a joint in a row, value differs significantly ($P = 0.001$) from the value for the nonlame dogs.

contralateral limb ($P = 0.03$) of the dogs with osteoarthritis of the hip joints had a significant decrease in extension, compared with those of nonlame dogs (Table 1). There was a significant ($P = 0.04$) reduction in ROM of the hip joint between the contralateral limb of osteoarthritic dogs and the nonlame dogs during walking down the decline. When comparing hip joint kinematics of the lame limb versus the contralateral limb, it was found that flexion was significantly ($P = 0.04$) reduced in the contralateral limb. Compared with the mean ± SD duration of the swing phase for the left hind limb of the nonlame dogs (51.65 ± 3.0%), mean duration in the dogs with osteoarthritis of the hip joints was significantly shorter for the lame limb (43.06 ± 6.8%; $P = 0.004$) and contralateral limb (42.12 ± 7.2%; $P = 0.003$). No significant ($P = 0.53$) differences were detected between the lame limb and the contralateral limb in the dogs with osteoarthritis of the hip joints.

Walking over obstacles did not change hip joint kinematics of the dogs with osteoarthritis of the hip joints. In contrast, maximal flexion of the stifle joint was increased significantly ($P = 0.03$) for the contralateral limb but not significantly ($P = 0.08$; statistical power, 54.4%) for the lame limb (Table 1). There was a significant ($P = 0.04$) increase in ROM between the stifle joint of the contralateral limb of osteoarthritic dogs and the stifle joint of the evaluated limb of the nonlame dogs during walking over obstacles. Also, maximal flexion was significantly increased in the tarsal joint of the lame limb ($P < 0.001$) and contralateral limb ($P = 0.02$) in the dogs with osteoarthritis of the hip joints, which resulted in a significant ($P = 0.04$) increase in ROM between the tarsal joint of the lame limb of osteoarthritic dogs and the tarsal joint of the nonlame dogs. Additionally, in the dogs with osteoarthritis of the hip joints, maximal extension of the tarsal joint of the contralateral limb was significantly ($P < 0.001$) decreased, compared with maximal extension of the tarsal joint in the nonlame dogs. No significant differences were found between the lame limb and contralateral limb of dogs with osteoarthritis of the hip joints.

No differences in the mean ± SD duration of the swing phase were detected between the nonlame dogs and the dogs with osteoarthritis of the hip joints (left hind limb of nonlame dogs, 43.64 ± 4.7%; lame limb of dogs with osteoarthritis of the hip joints, 45.05 ± 5.4%; contralateral limb of dogs with osteoarthritis of the hip joints, 44.69 ± 5.0%). No significant ($P = 0.76$) differences were detected between the lame limb and the contralateral limb of dogs with osteoarthritis of the hip joints.

Discussion

Analysis of the results of the present study allowed us to accept our hypothesis that dogs with osteoarthritis of the hip joints have specific changes of joint kinematics when performing special exercises, compared with values for nonlame dogs. Each of the investigated exercises had a specific impact on the joints. Walking up an incline or down a decline requires special abilities, such as shifting of the body's center of mass, accurate control of all joints to enable a stable gait pattern, prevention of falling or slipping, and increasing muscle work. In humans, studies have been performed to address this topic. For example, investigators in 1 study[19] found that in healthy subjects walking up an incline and down a decline, flexion of the hip joint at heel strike was lower (25° on a decline of −10°) during walking down the decline than during walking up the incline (58° on an incline of 10°), whereas flexion of the knee joint and dorsiflexion of the ankle joint at heel strike increased during walking up the incline (knee joint, 33° on an incline of 10°; ankle joint, 9° on an incline of 10°) but not during normal walking (knee joint, 7° on a horizontal surface [0°]; ankle joint, 5° on a horizontal surface). These results are in accordance with findings in cats, in which hind limb joints are more flexed at paw contact with an increase in the slope of an incline.[20] For nonlame dogs, investigators found that flexion of the hip joint decreased during walking down a decline (flexion, 11°) and increased during walking up an incline (flexion, 15.1°), compared with joint flexion during walking on a horizontal surface (flexion, 13.0°).[15] The stifle joint had a decrease in extension at the transition between the swing and stance phases (walking on a horizontal surface, 18.5°; walking up an incline, 13.1°), which again leads to a more flexed position of the joint at this moment.

An interesting change in movement pattern of the tarsal joint can be seen when comparing walking up an incline or down a decline. There is maximal extension of the tarsal joint at the time of body propulsion to push the body forward during walking up an incline and at the end of the swing phase to bring the paw to the ground during walking down a decline. These alterations indicate the mechanisms necessary to shift the body's center of mass and to deal with the proprioceptive demands of walking on slopes. When the nonlame dogs were compared with the dogs with osteoarthritis of the hip joints during walking up the incline, no differences were detected between the hip joint of the lame limb in the osteoarthritic dogs and the left hind limb of the nonlame dogs. However, extension of both hip joints of the dogs with osteoarthritis of the hip joints was reduced during walking down the decline. There is maximal extension of the hip joint at the transition between the stance and swing phases during body propulsion. Extension of the hip joint typically causes pain for animals with osteoarthritis of the hip joints, and this was also evident in the affected dogs in the present study. The contralateral hip joint had decreased flexion. The most likely explanation for this is the bilateral nature of hip joint osteoarthritis in the affected dogs. The dogs with osteoarthritis of the hip joints typically had a reduction in ROM of the hip joints during walking down the decline. It is conceivable that this was caused by the higher forces exerted on the limb during walking down a slope. The reduced ROM could further be considered a result of higher muscle activity of the hip joint contractors, and future studies should focus on muscle activity patterns during normal walking and special exercises.

A comparable situation was found regarding the stifle joint during walking up the incline. When walking up the incline, dogs with osteoarthritis of the hip joints had decreased extension of the stifle joint at the transition between the swing and stance phases, which leads to a more flexed position of the stifle joint during touchdown of the paw. The reduced extension at touchdown of the paw might lead to a more stable position of the stifle joint, and the study of muscles (eg, the quadriceps muscle and the hamstring muscle group) of nonlame and orthopedically impaired dogs could provide valuable insights into canine biomechanics. The decreased duration of the swing phase may have been attributed to the need to prevent slipping.

Walking over low obstacles caused increased flexion of the tarsal and stifle joints and greater extension and ROM of the stifle joint, compared with results for nonlame dogs during normal walking.[15] In the dogs with osteoarthritis of the hip joints, flexion of both tarsal joints was increased, compared with flexion in the nonlame dogs; furthermore, ROM of the lame limb increased, and extension of the tarsal joint in the contralateral limb decreased. This complex change may have been attributable to the accurate control of the swinging limb and simultaneous control of body balance, such as when walking over obstacles. This is additionally hindered by the fact that the obstacle is out of the field of vision as soon as the forelimbs pass over the obstacle. Without visual feedback regarding the relative position of the limb to the obstacle, control of the movement is more difficult if the neuromuscular system is impaired by injuries or disorders. In humans, it is known that osteoarthritis has an impact on proprioception.[21] Investigators in 1 study[22] found that humans patients with osteoarthritis of the knee joint use a smaller flexion of the knee joint to successfully walk over obstacles and avoid falling. Interestingly, dogs appear to use another mechanism in that they increase flexion of the stifle and tarsal joints. This is in accordance with the results of another study[12] in which investigators found that dogs (which are quadrupeds) use different kinematic mechanisms for climbing stairs than do humans (who are bipedal).

Results of the study reported here might have been influenced by various factors, especially because skin movement is a notoriously difficult problem in gait analysis.[23,24] Therefore, with use of markers affixed to the skin over anatomic locations, it is impossible to identify slight alterations in joint kinematics. One possible solution for this problem could be surgical fixation of the markers, but this procedure is controversial because of ethical reasons. Also, differences in age and body confirmation between dogs could be a factor masking subtle alterations of joint kinematics, considering that different breeds have differences in the amplitude of moment and power patterns of the stifle and tarsal joints.[25] Furthermore, body confirmation influences the GRF of the forelimbs, probably as a result of changes in the center of mass.[26] This could be especially important during walking on inclines and declines. Difference in body weight between groups must also be considered. It was remarkable that GRFs of the lame limbs in the dogs with osteoarthritis of the hip joints were similar to the values of the limbs in the nonlame dogs, whereas the contralateral limbs had higher values. This may have been attributable to the difference in body weight between the groups; it is possible that changes in the kinetics of obese animals differ from those in normal-weight animals. This topic requires further research, including the investigation of the relationship among the amount of body fat, body weight, and body condition score and their influence on the GRF of nonlame and orthopedically impaired animals.

To substantiate the results of the study reported here, a larger number of dogs (of the same breed, body weight, and age, if possible) should be investigated. Because of the small sample size and the corresponding limited statistical power for this study, it should be mentioned that a high β error exists.

A new, interesting aspect regarding comparisons between the left and right limbs has been introduced.[27] In that study,[27] investigators found that even nonlame dogs can have asymmetries in limb and joint mechanics, and further studies must be conducted to determine how this information should be considered when comparing results for nonlame and affected animals. This fact gains importance because the difference in the amplitudes between nonlame and osteoarthritic dogs in the present study was small. This might also be related to the fact that the degree of lameness influences the manifestation of kinematic changes; therefore, it would be of great interest to compare dogs with different types of lameness and lameness with a higher severity than those used in the present study. The question arises as to whether the changes in amplitude are sufficient to warrant application or avoidance of specific exercises. In fact, this question can only be answered if studies are conducted to investigate treatment outcome. In contrast, small but continuous movements of a diseased joint may have a more effective impact on the joint kinematics than movements with great amplitudes, which might have the potential for the risk of further joint damage.

Clinical evaluation revealed signs of pain in both hip joints of all dogs, but the pain score varied, and the degree of lameness was not the same in each dog. This fact was also reflected by evaluation of the SI; nevertheless, we assumed that the slight differences detected in the degree of lameness did not markedly influence the results. Unfortunately, the number of dogs used in the study was too low to provide subgroups with more homogeneity, but this should be addressed in future studies.

Analysis of the results of the present study indicates that osteoarthritis of the hip joints leads to complex changes in gait patterns, which involve more joints than the affected hip joints. In future studies, it would be of interest to investigate the effect of pelvic limb lameness on lumbar motion or the position of the pelvis in relation to the vertebral column in lame and nonlame animals. The exercises used in the present study have specific value in physical therapy. Walking over low obstacles may be useful to increase the flexion of the tarsal and the stifle joints and to train the proprioceptive abilities of an animal. Walking up an incline may be useful to strengthen the muscle groups involved in pushing the body forward against gravity. However, therapists must be aware that extension of the stifle joint is reduced in affected animals and that other exercises (eg, stretching) should be used if improvement of the stifle joint ROM is an intended goal. As suspected in another study[15] conducted by our laboratory group, walking down a decline does not appear to have a positive impact on osteoarthritic hip joints, especially because it leads to decreased extension of the hip joints.

a. EVaRT, version 5.0.4, Motion Analyses Corp, Santa Rosa, Calif.
b. Excel, Microsoft Office 2007 for Windows, Microsoft Corp, Redmond, Wash.
c. MatLab, version 7.4.0.287 (R2007a), The Mathwork, Natick, Mass.
d. SPSS, version 14.0, SPSS Inc, Chicago, Ill.

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