Military working dogs are of great importance for human safety when used to detect narcotics, explosives, or the location of the source of arson. They also play essential roles as patrol and guard dogs. A great deal of stress is put on the musculoskeletal system of MWDs during work. Hip dysplasia and secondary osteoarthritis have been reported as the most common reason for euthanasia or departure from active service in MWDs.1 Dogs with radiographic evidence of HD typically are not selected for military or police work, but a few dogs with mild to moderate HD have been accepted into MWD training programs.1 Investigators in 1 study2 determined that degenerative joint disease resulting from HD did not significantly influence the number of months dogs were able to work, compared with the number of working months for nondysplastic dogs. Those authors attributed their results to the low morbidity of the degenerative joint disease for that study and advances in medical management of HD. Nevertheless, dysplastic dogs have a significantly greater risk for developing degenerative joint disease, compared with the risk for clinically normal dogs, and diseases of the skeleton are the most important problem in the MWD population.3

Because of the enormous costs associated with the training of MWDs, it is imperative to use advances in veterinary diagnostic techniques to help detect orthopedic problems as soon as possible, thereby maximizing the working life of MWDs. Kinetic and kinematic gait analyses have been used widely to describe normal and pathologic gaits in dogs. Kinetic gait analysis performed by the use of force plates is easy to perform, and the results are valid for this reproducible method.4-10 Kinetic gait analysis is used in basic and clinical research, and several studies11-16 have been published in which researchers investigated HD.

In contrast to the use of GRFs, which provide information only about the summation of forces acting on the entire limb, kinematic analysis provides information
about the function of each of the joints separately. Only a few studies\textsuperscript{17,18} have described the influence of HD on joint kinematics. In one of those studies,\textsuperscript{18} investigators detected subtle but significant alterations in joint kinematics in a nonhomogeneous group of lame dogs. In that study, the affected hip joint had an increase in extension and velocity at the end of the stance phase but the stifle and tarsal joints also had alterations, compared with results for clinically sound dogs. In another study,\textsuperscript{17} investigators found additional kinematic variables (such as joint adduction) that could be used to describe clinical signs of HD. To the authors’ knowledge, no studies have been published on whether clinically sound dogs with radiographic signs of HD also have altered joint kinematics. Therefore, the objective of the study reported here was to investigate changes in joint kinematics in the hind limbs of clinically sound dogs with radiographically diagnosed borderline HD.

Materials and Methods

**Animals**—20 Belgian Shepherd Dogs (Malinois) used as working dogs for the Department of Defence of the Republic of Slovenia were included in the study. Age of the dogs ranged from 1.5 to 11 years (mean ± SD, 2.75 ± 1.32 years), and body weight ranged from 21 to 32.6 kg (mean, 28.61 ± 3.37 kg). Seventeen dogs were males, and 3 were females. All dogs underwent thorough orthopedic and neurologic examinations and were considered clinically sound when lameness was not visibly evident and pain or discomfort were not detected during manipulation and palpation of joints, muscles, and the vertebral column. To substantiate clinical findings, an analysis of GRFs of the hind limbs was performed. The study was approved by the ethical and animal welfare commission of the University of Veterinary Medicine, Vienna, Austria.

**Classification of HD**—Radiographs of the hip joints were obtained by personnel at the Veterinary University of Ljubljana, Slovenia. Radiographic views were evaluated by one of the authors (WH) and interpreted in accordance with guidelines of the Fédération Cynologique Internationale (Appendix). Dogs were classified into 2 groups (group 1, no radiographic signs of HD; and group 2, dogs with radiographic signs of borderline HD).

**Motion analysis**—Light-reflective spherical markers (1.5 cm in diameter) were placed on the skin overlying the iliac crest, greater trochanter, stifle joint between the lateral epicondyle of the femur and fibular head, lateral malleolus, and distal aspect of the fifth metatarsal bone of both hind limbs. To determine the motion cycle, spherical markers were placed on the distal aspect of the fifth metacarpal and metatarsal bones of all 4 limbs.

Movement in walking dogs was recorded by use of 4 cameras\textsuperscript{19} that were positioned at a distance of 2 m and height of 80 cm around a treadmill.\textsuperscript{19} The treadmill contained 4 biomechanical force plates, which allowed measurement of vertical GRF. Sample frequency of the camera was 50 Hz, and accuracy of the synchronization was 1 millisecond. For each session, the system was calibrated with a calibration frame of known dimensions. Data were analyzed by use of a motion-analysis program.\textsuperscript{20}

**Data collection and analysis**—Before beginning the experiments, dogs were allowed an acclimation period during which they were trained to walk on the treadmill. Dogs were always handled by the same person. The treadmill was started at a low speed, and velocity was increased gradually until a dog had a smooth, well-coordinated walk. Speed of the treadmill was 1.22 m/s. To detect underlying lameness not evident during the clinical examination, GRFs were measured, and 5 steps were evaluated for each dog. Variables evaluated were PF\textsubscript{z} and IF\textsubscript{z}, both of which were adjusted on the basis of the body weight for each dog and averaged for the 5 steps. Weight distribution between the hind limbs was calculated for each variable by use of the following equation:

\[
\Delta \% \text{LH/RH} = \left( \frac{\text{VFz}_{\text{LH}} - \text{VFz}_{\text{RH}}}{\text{VFz}_{\text{LH}} + \text{VFz}_{\text{RH}}} \right) \times 100
\]

where \(\Delta \% \text{LH/RH}\) is the difference in weight distribution between the hind limbs, LH is the left hind limb, RH is the right hind limb, and \text{VFz} is the mean of the given variable (ie, PF\textsubscript{z} or IF\textsubscript{z}). Dogs were considered to be free of lameness when \(\Delta \% \text{LH/RH}\) was ≤ 3%. In an ensuing analysis, GRF values of dogs with lameness were compared with values of nonaffected dogs to exclude the potential for bilateral lameness.

**Kinematic analysis**—As soon as each dog achieved a smooth gait pattern, videotaping was initiated. Five motion cycles were analyzed within the measurement period. To detect differences in the speed of each dog, the duration of the motion cycle of the right forelimb was calculated. The 3-dimensional coordinates of each marker were determined from the videotape data and processed by the motion-analysis software. Processed data were then transferred to a computer spreadsheet program\textsuperscript{4} for use in additional calculations. One motion cycle was defined as the period between the first and third zero positions of the horizontal speed of the paw marker. Duration of each cycle was standardized to 100 time frames (ie, percentage of the motion cycle).

**Evaluation of angles**—Angles of the hip, femorotibial, and tarsal joints were calculated in the sagittal plane for each time frame of 5 motion cycles of each dog. From the 5 motion cycles evaluated for each dog, the individual angle or time curve was determined for each dog. Each motion cycle was adjusted to a neutral position to correct small differences in placement of markers among dogs.

Variables evaluated were maximum extension and maximum flexion during the motion cycle and the time at which maximum extension and maximum flexion were detected. Range of motion was calculated as maximum extension minus maximum flexion. Angle velocity was determined, and the maximal and minimal velocity and the time at which maximal and minimal velocity were detected were calculated.

**Statistical analysis**—Dogs were assigned to 2 groups (group 1, no radiographic signs of HD [con-
Results

Animals—On the basis of radiographic examination, 8 dogs (mean ± SD age, 2.25 ± 1.06 years) were classified in group 1 (ie, no radiographic signs of HD). The remaining 12 dogs (mean age, 3.25 ± 1.77 years) were classified in group 2 (ie, radiographic signs of borderline HD). Treadmill speed did not differ significantly between the groups as determined by evaluation of the mean ± SD cycle time of the right forelimb (group 1, 0.9 ± 0.03 seconds; and group 2, 0.9 ± 0.1 seconds).

Analysis of GRF values—Mean of the GRF values was calculated for each of the groups. For group 1, mean ± SD PFz of the left hind limb was 41.20 ± 3.8% of body weight, whereas mean PFz of the right hind limb was 40.9 ± 7.4% of body weight. Mean IFz of the left and right hind limbs was 18.4 ± 2.9% and 18.6 ± 3.4% of body weight, respectively. For group 2, mean PFz of the left hind limb was 40.4 ± 3.7% of body weight and PFz of the right hind limb was 40.4 ± 3.1% of body weight. Mean IFz of the left and right hind limbs was 17.3 ± 1.6% and 17.7 ± 2.2% of body weight, respectively. Differences in weight distribution between the hind limbs ranged from 0.20% to 4.75% (mean, 1.98 ± 1.34%) for PFz and from 0.19% to 5.13% (mean, 2.06 ± 1.40%) for IFz. None of the values differed significantly between the 2 groups.

Joint angle and angular velocity for the hip joints—Nine variables were used to characterize angle
kinematics and angular velocities of the hip joints (Tables 1 and 2). Mean motion pattern of the hip joints for both groups was plotted (Figure 1). Maximal flexion in the swing phase was detected significantly ($P = 0.02$) earlier for dogs of group 1, compared with the value for dogs of group 2.

Joint angle and angular velocity for the femorotibial joints—Variables for joint angle and angular velocity of the stifle joints for both groups were calculated (Tables 1 and 2). Mean motion pattern of the stifle joints of both groups was plotted (Figure 2). Analysis of angular velocity data revealed a significantly ($P = 0.02$) higher maximal value for flexion during the swing phase for group 2, compared with the value for group 1.

Discussion

In the study reported here, we determined that even subclinical and subtle radiographic signs of HD can influence joint kinematics of Belgian Shepherd Dogs. In other studies, motion analysis of dogs with clinical signs of HD revealed complex alterations in joint kinematics and GRFs. By use of GRF analyses, it has been reported that dogs with HD (Fédération Cynologique Internationale classifications C, D, and E) have significantly lower vertical GRFs than clinically normal dogs, even when the dogs with HD had no clinical signs.

However, GRFs provide information only about the summation of forces acting on the limb during the stance phase. Therefore, they are not suitable for describing the characteristics of single joints and the influences of HD on the stifle and tarsus joints in addition to the hip joints. For characterization of these complex biomechanical alterations, the use of dynamic kinematic analysis is required. In another study, dynamic kinematic analysis revealed that clinically evident HD influences many kinematic variables of the hind limbs. For example, the hip joints had a higher degree of extension during the late portion of the stance phase in dogs with HD, and stifle and tarsal joints had higher values for flexion during certain parts of the stance and swing phases, compared with values for clinically normal dogs. In addition, there were changes in angular velocity in affected dogs in that study, which revealed higher velocities of flexion and extension in various parts of the motion cycle.

Some of the aforementioned results appear to agree with our observations. Maximal flexion of the hip joints was detected significantly later during the swing phase in affected dogs, compared with results for dogs without HD. Also, the femorotibial joints had an increase in flexion and ROM in dogs with borderline HD, and angular velocities during maximal flexion accelerated significantly faster in the stifle and tarsal joints in dogs with borderline HD. The
main difference between the study reported here and a study\textsuperscript{18} conducted by other investigators is the fact that the dogs examined in our study did not have clinical signs of HD. Analysis of our findings suggests that a lack of visible lameness and evidence of pain during manipulation does not exclude altered biomechanics in joints as a result of HD. These subtle changes suggest complex compensatory mechanisms and interactions between joints of the involved limb. Nevertheless, some findings in that other study,\textsuperscript{18} such as the increased extension during the late portion of the stance phase, are not supported by the results of the study reported here, which may be explained by the fact that the dogs of our study did not have lameness.

The results of our study must also be interpreted with regard to the classification method. Currently, use of the Norberg angle is the criterion-referenced standard in most European countries and is mandatory in such cases. Nevertheless, it has been strongly suggested in some studies\textsuperscript{19,20} that another method\textsuperscript{21} is superior to the Norberg angle for use as a predictor of susceptibility to degenerative joint disease. Therefore, we recommend that additional studies be conducted that explicitly focus on comparisons of various classification schemes with kinematic measurements. It is also possible that our study protocol may have caused differences in results. Although the use of a treadmill is a valid method for the measurement of GRFs\textsuperscript{8,10} and kinematics\textsuperscript{22} in dogs, it is obvious that walking on a treadmill differs from walking on the ground and therefore influences movement patterns. This has been reported for humans\textsuperscript{23} and horses,\textsuperscript{24} but studies defining the exact differences between walking on a treadmill and on the ground in healthy dogs or dogs with orthopedic disorders are lacking. Despite these limitations, use of a treadmill system provides some advantages over measurements obtained from normal ground walking. Biomechanics of a limb are highly correlated with gait velocity, especially for GRFs in dogs.\textsuperscript{24,26} Use of a treadmill enables measurement with the same velocity throughout a study; therefore, differences among and within dogs as a result of differences in walking velocities can be excluded.

The impact of skin movement on measurements requires critical evaluation. Investigators in 1 study\textsuperscript{27} reported that movement of the skin can influence kinematic variables. The only possibility for circumventing this negative influence on measurement would be the use of bone pins. Practicality and animal welfare concerns limit the use of bone pins in clinical studies.

Results of the study reported here may serve as the basis for additional studies in which joint kinematics are compared between animals with similar morphometric characteristics with or without radiographic alterations. In addition, long-term studies can be conducted that evaluate the clinical relevance of our results. This may be of major importance for the assessment of health status in valuable working dogs. Use of modern diagnostic procedures for preventive medical care programs will help MWDs achieve maximum working time.

References


Appendix

Classification of HD in dogs by use of guidelines established by the Fédération Cynologique Internationale.

<table>
<thead>
<tr>
<th>Grade</th>
<th>Norberg angle (°)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>≥ 105</td>
<td>Femoral head and acetabulum are congruent, craniolateral rim appears sharp and slightly rounded, and joint space is narrow and even. In excellent hip joints, the craniolateral rim encircles the femoral head slightly more in a laterocaudal direction.</td>
</tr>
<tr>
<td>B</td>
<td>100–105</td>
<td>Femoral head and acetabulum are slightly incongruent. Femoral head and acetabulum are congruent.</td>
</tr>
<tr>
<td>C</td>
<td>≥ 100</td>
<td>Femoral head and acetabulum are incongruent, or there is a slightly flattened craniolateral rim; irregularities are only mild osteoarthritic changes of the cranial, dorsal, or caudal acetabular margins; and irregularities may be evident on the femoral head and neck.</td>
</tr>
<tr>
<td>D</td>
<td>&gt; 90 (as reference)</td>
<td>Obvious incongruence between femoral head and acetabulum with subluxation and flattening of cranio-caudal rim or osteoarthritic signs are evident.</td>
</tr>
<tr>
<td>E</td>
<td>≤ 90</td>
<td>Marked dysplastic changes (e.g., luxation or distinct subluxation, obvious flattening of the cranial acetabular margin, or deformation of the femoral head [mushroom shaped or flattened]) or other signs of osteoarthritis.</td>
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