Use of an inverse dynamics method to describe the motion of the canine pelvic limb in three dimensions

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Objective—To use an inverse dynamics method to describe the motion of the canine pelvic limb in 3 dimensions.

Animals—6 healthy adult dogs.

Procedures—For each dog, 16 anatomic and tracking markers were used to define the center of rotation for the pelvic limb joints and a kinematic model was created to describe the motion of the pelvic limb. Kinetic, kinematic, and morphometric data were combined so that an inverse dynamics method could be used to define angular displacement, joint moment, and power of the hip, stifle, and tibiotarsal (hock) joints in the sagittal, frontal, and transverse planes.

Results—Movement and energy patterns were described for the hip, stifle, and hock joints in the sagittal, frontal, and transverse planes.

Conclusions and Clinical Relevance—Knowledge of the 3-D movement of the pelvic limb can be used to better understand its motion, moment, and energy patterns in healthy dogs and provide a referent with which gaits of dogs with pelvic limb injuries before and after surgical repair or rehabilitation can be compared and characterized. This information can then be used to guide decisions regarding treatment options for dogs with pelvic limb injuries. (Am J Vet Res 2014;75:544–553)

The use of inverse dynamics to describe gait is relatively new to veterinary medicine. Historically, research of gait in dogs relied on ground reaction force and kinematic data. Results of studies1,2 that evaluated kinetic changes, specifically ground reaction forces, provided objective measurements and helped elucidate the pathological gait of dogs with osteoarthritis in the hip and stifle joints. Investigators of other studies3,4 used kinematic descriptions to better define changes in gait associated with osteoarthritis in the hip and stifle joints of dogs. Inverse dynamics combines kinetic and kinematic data to provide a more comprehensive description of gait.

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EMG Electromyography

Studies5–9 to investigate the 3-D movement of the canine stifle joint are limited, and only 1 study6 investigated the 3-D movement of the hip, stifle, and tibiotarsal (hock) joints. Other studies5,7,8 were conducted to describe the motion of the stifle joint alone, and it is difficult to compare results obtained by use of inverse dynamics with those studies because they involved the use of cadavers5 or invasive methods for data collection,7,8 which makes extrapolation of data for clinical application difficult. In only 2 studies5,9 were contemporary, clinically applicable methods used to obtain data to define the motion of the canine pelvic limb joints in 3 dimensions.

When considered separately, results of force plate and kinematic analyses cannot be used to comprehensively describe the joint kinetics (eg, joint movement and power) of dogs. Inverse dynamics combines kinetic, kinematic, and morphometric data to provide a more comprehensive description of the causes of movement patterns at both the joint and muscle group levels; however, it has been used infrequently to help describe the motion of the canine pelvic limb.10–13 Currently, investigators of only 1 study12 have reported morphometric data for the canine pelvic limb in conjunction with a comparison of the power distribution across the pelvic limb.
between Labrador Retrievers and Greyhounds. The inverse dynamics method has been used to eluc-
idate the asymmetry, or handedness, of dogs and assess the gait of dogs before and after total hip re-
placement. To our knowledge, an inverse dynamics method has not been used to describe the 3-D move-
ment of the canine pelvic limb. Therefore, the purpose of the study reported here was to describe the
use of an inverse dynamics model novel to veterinary medicine to analyze the 3-D movement of the pelvic
limbs of healthy dogs. This model estimates the cen-
ter of rotation for each joint, which allows for a more
accurate description of the motion in the hip, stif-
le, and hock joints in 3 planes.

Materials and Methods

Animals—The study protocol was approved by the
University of Tennessee Institutional Animal Care and
Use Committee. Six hound-type dogs were used in the
study. The mean ± SD weight of the study dogs was
22.6 ± 1.1 kg (range, 21.5 to 24.6 kg). All dogs were
determined to be healthy with no evidence of gait,
orthopedic, or neurologic abnormalities on the basis
of physical examination results. Radiographic exami-
nation of the caudal portion of the vertebral column,
pelvis, and pelvic limbs of each dog revealed that none had
evidence of osteoarthritis in the pelvic region.

Computer skeletal model—A commercial ge-
eric canine skeleton model file was resized and trans-
formed to make it compatible for the analysis of
an individual dog’s movements with 3-D biomech-
anics software. The reconfigured 3-D skeleton model
was used to visually assess the individual 3-D test models
and provided a realistic evaluation of the motion of
each segment (pelvis, femur, tibia, and foot) of the pel-
vic limb (Figure 1).

Instrumentation of dogs—Each pelvic limb was eval-
uated separately. During each examination, each
dog was instrumented with spherical (diameter, 14 mm)
reflective anatomic and tracking markers. Anatomic
markers were used to define the approximate locations
of the proximal and distal centers of rotation (joint cen-
ters) for each limb segment. The hair was shaved from
the pelvic limb locations where 16 markers were to be
placed for monitoring the 3-D movements of each limb
segment. The markers were attached to each dog with
cyanoacrylate adhesive at the distal aspect of the sec-
ond and fifth metatarsal bones, medial and lateral mal-
leoli, medial and lateral condyles of the femur, the
proximate midway between the stifle and hip joints, and
hock joints in 3 planes.

was performed with the dogs restrained in a station-
ary standing position in the testing area. During this
calibration, all 16 markers were visible by at least 2 of 4
video cameras and a 3-second video of the standing dog
was obtained (Figure 2). After the static calibration
was completed, the anatomic markers on the medial aspect
of the foot and hock and stifle joints were removed as
were those (ie, ischium, ilium, and greater trochanter of
the femur) on the pelvis and pelvic limb contralateral to
the limb being evaluated.

Experimental protocol—Kinetic and kinematic
data were collected simultaneously during dynamic
movement trials. Kinetic data were obtained with a
1,000-Hz force platform that was mounted in the cen-
ter of and flush with a 10.68-m runway. The force plat-
form signal was processed and stored by use of a spe-
cialized computer software program. Kinematic data
were obtained with a 60-Hz, 4-camera, 3-D motion
capture system. Prior to each data collection period,
the 3-D space was calibrated with a calibration frame
and a wand.

Figure 1—Screenshot of a full-body skeletal model of a dog de-
developed by a 3-D computer software program that depicts place-
ment of anatomic markers for collection of kinematic data. For
the dogs of the present study, markers were not placed over the
skull, forelimb, and thoracic and lumbar portions of the vertebral
column. The mediolateral (X), craniocaudal (Y), and vertical (red
arrow) components of the ground reaction force are indicated.

Figure 2—Representative photographs of an adult hound-type
dog that depicts the placement of 16 reflective markers (white
circles) for monitoring the 3-D movement of the right pelvic limb.
The markers were placed at the distal aspect of the second and
fifth metatarsal bones, medial and lateral malleoli, medial and
condyles of the femur, greater trochanter of the left and right femurs,
and left and right ischial tuberosities of the pelvis, and the most dor-
als aspect of the right ilial bones of the pelvis. All 16 markers were
visible at all times by at least 2 of 4 video cameras used to obtain kinematic data.
After removal of the anatomic markers, dogs were trotted through the test space and over the forceplate at a mean velocity between 1.7 and 2.1 m/s and mean acceleration between –0.5 and 0.5 m/s². Velocity and acceleration were monitored by 5 infrared photoelectric cells that were placed 30 cm apart from each other along the middle portion of the test space, each of which sent a signal to a computer software program when the dog passed it. The software program automatically calculated the mean velocity and acceleration on the basis of the distance between the photoelectric cells and the time that elapsed between each successive signal. For each pelvic limb, data were obtained for 5 successful, or valid, trials. A valid trial was defined as a passage over the runway in which there was no aberrant movement of the subject’s head or body in the calibrated space, the velocity and acceleration were within the established ranges, the fore and hind paws ipsilateral to the side being evaluated both struck the forceplate, and all tracking markers were visible by at least 2 cameras at all times. Stance time was defined as the time between toe-on and toe-off and was measured by movement of the marker on the dorsal aspect of the foot in the sagittal plane. Mediolateral, craniocaudal, and vertical components of the ground reaction force were assigned values of x, y, and z respectively. These forces were normalized to the subject’s body weight and were reported as a percentage of the body weight. The same investigator (JFH) applied all the markers to the dogs during all testing sessions, and the same handler (RPM) trotted the dogs during all trials. A Cardan sequence (x-y-z) was used to compute 3-D angular kinematics. The conventions of 3-D angular kinematic and kinetic variables were determined by use of a right-hand rule.

**Data processing**—Kinetic data were processed by custom software, and kinematic data were processed by a commercially available motion analysis system. Another custom software program was used to combine the kinetic and kinematic data. The 3-D coordinates of marker trajectories were smoothed by a Butterworth fourth-order low-pass filter with a cutoff frequency of 6 Hz. The synchronized data were processed, computer models were created and analyzed, and reports were produced with commercially available software. The outputs from that software were analyzed with customized computer programs to identify critical events and values of the computed variables. Morphometric data for Labrador Retrievers, including each segment’s (pelvis, femur, tibia, and foot) percentage of body weight and center of gravity, obtained from another study, were input into the 3-D software used for the inverse dynamics calculations. Although the investigators of that other study reported morphometric data for both Labrador Retrievers and Greyhounds, we chose to use the morphometric data for Labrador Retrievers and Greyhounds because the body form of the hound-type dogs used in the present study was more similar to that of Labrador Retrievers than to that of Greyhounds.

Virtual markers representing the joint centers of the hip, stifle, and metatarsophalangeal joints were mathematically reconstructed with software on the basis of information regarding the location of the anatomic markers obtained during the static calibration. The center of rotation for each of the hip, stifle, and hock joints was reconstructed with a virtual marker that was configured by 2 distinct means. The virtual marker for the hip joint was designated to be on a line that connected the markers on the greater trochanter of both femurs and was programmed to be placed at a point medial to the marker on the greater trochanter of the side being evaluated. This point was specific for each dog and defined on the basis of measurements obtained from the ventrodorsal pelvic radiograph; a line was drawn on the digital radiograph between the greater trochanter of each femur, with the ends of that line corresponding to the placement of the anatomic markers on the greater trochanters. For the pelvic limb being evaluated, another line was drawn from the greater trochanter beginning at the origin of the first line and ending at a point that approximated the coxofemoral articulation. The ratio of the measurements of the first line to the second line was used to program the location of the virtual marker medial to the marker on the greater trochanter. Data obtained during the static calibration were used to define the centers of rotation for the stifle, hock, and metatarsophalangeal joints; each joint’s center of rotation was mathematically determined as the point midway between the lateral and medial anatomic markers for that joint.

Joint angles, moments, and powers in the sagittal, frontal, and transverse planes during the stance phase of the gait cycle were evaluated. The moments and powers were normalized by the mass of each dog resulting in units of newton-meters per kilogram (Nm/kg) and watts per kilogram (W/kg), respectively. Joint angles were computed as motions of the distal segment relative to the motions of the proximal segment. The range of motion was defined as the angular displacement of a joint throughout the stance phase (ie, toe-on to toe-off). Joint excursion was defined as the difference between the maximum and minimum joint angles during the stance phase. In the sagittal plane, a positive moment was assigned to those moments across the cranial aspect of the pelvic limb (hip joint flexors, stifle joint extensors, and hock joint extensors). In the frontal plane, a positive moment was assigned to those moments associated with adduction and a negative moment was assigned to moments associated with abduction. In the transverse plane, a positive moment was assigned to those moments associated with internal rotation and a negative moment was assigned to moments associated with external rotation. A positive power indicated power generated by the muscles across the joint and was represented as concentric muscle contraction or shortening of the muscle fibers during tension generation. A negative power represented eccentric contraction or lengthening of the muscle fibers during tension generation and was indicative of energy absorption at the joint. The moments computed through inverse dynamics were net moments across a joint. For all dogs, mean joint an-
gular excursions, net joint moments, and net joint powers were determined and mean curves were generated in the sagittal, frontal, and transverse planes for the hock, stifle, and hip joints.

Results

Sagittal plane dynamics—The mean curves for the angles, moments, and powers of the hock, stifle, and hip joints in the sagittal plane were summarized (Figure 3). For the hock joint, the mean kinematic curve indicated that the joint began the stance phase in flexion and continued to flex during the initial 40% of the phase and then changed toward extension for the remainder of the phase. Through-
out the stance phase, there was a net extensor moment with an increase in torque (moment of force) for the first 40% of the phase followed by a decrease in torque during the remainder of the phase. Energy was absorbed during the first 40% of the stance phase, which indicated lengthening and eccentric contraction of the extensor muscles. This muscle action resulted in storage of elastic energy and consequently increased the concentric muscle contraction that propelled the hind limb during the remaining 60% of the stance phase as evidenced by the generation of energy (power > 0 W/kg) in the mean power curve during the second half of the stance phase.

The stifle joint began the stance phase in flexion and continued to flex for approximately the first 60% of the phase and then went into extension for the remainder of the phase. During the first 15% of the stance phase, the stifle joint had a net flexor moment, indicating that the biceps femoris, semitendinosus and semimembranosus muscles (hamstring muscles) were concentrically contracted. During the remainder of the stance phase, the stifle joint had a net extensor moment. The mean power curve had a negative power during the first half of the stance phase because of the eccentric contraction of the stifle joint extensors and a positive power during the second half of the stance phase when the stifle joint extensors transitioned to concentric contraction.

The hip joint was in continuous extension throughout stance phase. For the first half of the stance phase, the hip joint had a net extensor moment indicating concentric extensor contraction, which propelled the dog forward. For the second half of the stance phase, there was a net flexor moment indicative of energy absorption and eccentric contraction of the hip muscles, which slowed the limb in preparation for the swing phase.

Frontal plane dynamics—The mean curves for the angles, moments, and powers of the hock, stifle, and hip joints in the frontal plane were summarized (Figure 4). The hock joint was slightly abducted at the beginning of the stance phase but was adducted throughout the remainder of the stance phase. For most of the stance phase, the hock abductors were contracted eccentrically resulting in a net adductor moment and...
Similar to the hock joint, the stifle joint was slightly abducted at the beginning of the stance phase. During the first half of the stance phase, the stifle joint became slightly adducted and then underwent abduction during the second half of the stance phase. The stifle joint had a net abductor moment for the first 60% of the stance phase and a very slight adductor moment at the end of the stance phase. The stifle joint muscles were concentrically contracted throughout the stance phase.

The hip joint was abducted throughout the stance phase. The hip abductors caused a net abduction moment and were contracted concentrically throughout most of the stance phase.

Transverse plane dynamics—The mean curves for the angles, moments, and powers of the hock, stifle, and hip joints in the transverse plane were summarized (Figure 5). The hock joint began the stance phase in a slight internally rotated position and then rotated externally for most of the remainder of the phase. The external rotators of the hock joint contracted concentrically during the first 60% of the stance phase, which caused a net external rotation moment.

The stifle joint began the stance phase at a nearly neutral angle and externally rotated for the first 50% of the phase and remained in that position for the remainder of the stance phase. The internal rotator muscles of the stifle joint were eccentrically contracted, resulting in a net internal rotator moment for most of the stance phase; however, those muscles lengthened and absorbed energy as the tibia was externally rotated.

The hip joint began the stance phase in an externally rotated position and underwent internal rotation relative to the starting position for approximately the first 60% of the phase. During the remainder of the stance phase, the hip joint remained fairly stationary in the transverse plane. Most of the stance phase was characterized by eccentric contraction of the external rotators throughout joint excursion, although the external rotators did have small transitions from eccentric to concentric contractions throughout the phase.

Discussion
In the present report, we have described
Inverse dynamics combines kinetic (measurable) and solving for the applied muscle force and moment by mathematical integration; thus, the solution is to reverse the classic process of an object with known mass and calculation of the resultant motion by means of mathematical integration. However, in biological systems, the applied force by muscle contraction is unknown and immeasurable. Therefore, the solution is to reverse the classic process by beginning with a known motion (kinematic measure) and solving for the applied muscle force and the joint moment by mathematical integration; thus, the term inverse dynamics is used to describe such a process. Inverse dynamics combines kinetic (measurable ground reaction weight-bearing forces) and kinematic (changing joint angles) data with morphometric measurements (limb geometry) to solve for the joint moments responsible for creating a particular motion. Inverse dynamics computes the joint moment that caused joint rotations and joint power by combining the measurable information of ground reaction force, joint kinematics (angular position and velocity), and inertial properties of the segments of a limb (mass, mass moment of inertia, and center of mass location). The net moment of a joint is the net muscular moment produced by both agonist and antagonist muscles acting across the joint. The moment obtained from inverse dynamics designates which muscle group, flexor or extensor, is responsible for causing the net moment about a joint. This does not mean that both muscle groups are not active during an activity but rather indicates which group is predominately responsible for the net moment. The moment of inertia is the angular equivalent to mass and indicates an object's resistance to change in angular motion. An object's moment of inertia depends on both its mass and distribution of that mass with respect to the axis of rotation. The power across a joint is the rate of work (work/time) performed by the muscles, and it is determined by the moment multiplied by joint velocity. When the moment and velocity occur in the same direction, power is positive, which indicates concentric muscle contraction and the release of energy. When the moment and velocity occur in opposite directions, power is negative, which indicates eccentric muscle contraction and energy absorption.

In inverse dynamics, each segment of a limb acts independent of the others and is under the influence of muscle moments and reaction forces acting on either end as well as gravitational forces. Given known reaction forces, kinematics, and morphometric measurements of a distal segment, proximal joint reaction forces and limb muscle moments can be calculated.

Results of the present study indicated that in the sagittal plane, the inverse dynamics for the hock joint were similar to, whereas those for the stifle joint differed from, the results of another study that used the same morphometric data. The total joint angle excursion in the sagittal plane for the stifle joint was similar between that other study and the present one; however, in the present study, the mean flexion of the stifle joint was approximately 10° to 15° greater throughout the stance phase than that in the other study. Also, although the stifle joint had a concentric flexor moment in the sagittal plane at the beginning of the stance phase in both the present study and the other study, that moment had a longer duration in the other study. Additionally, results of the other study indicated that the stifle joint had no eccentric extensor contraction and only a very small amount of concentric extensor contraction in the sagittal plane during the stance phase. Results of subsequent studies conducted by that laboratory group indicate moment and power patterns for the stifle joint in the sagittal plane that more closely resemble those of the present study. The morphometric data used in the present study were the same as those used in those studies. Investigators that reported the morphometric data found moment and power differences between Greyhounds and Labrador Retrievers that they attributed, at least partially, to anatomic differences between the 2 breeds. It is possible that the anatomic differences between the Labrador Retrievers of that study and the hound-type dogs of the present study were responsible for the varying results between the 2 studies. However, we believe that the power results of the present study were consistent even though morphometric data from Labrador Retrievers were used for the calculations because of their similarity to the body type of the hound-type dogs used in this study. Moreover, results of inverse dynamics are proportional, and differences in morphometrics have only a minor role in joint moment and power because those calculations are predominately affected by ground reaction forces. Intuitively, it seems logical that the extensors have a period of eccentric activity during the stance phase prior to a period of concentric activity that propels the body forward. Further investigation is required to create breed-specific databases for further comparisons of motion and joint kinetic patterns between breeds of dogs.

Investigators of another study reported 3-D kinematics of the pelvic limb of dogs during a walk and trot and were the first to conduct a static trial and use estimates of the centers of rotation for various joints to describe canine limb motion in 3 dimensions. In that study, the hock joint in the sagittal plane was more flexed and did not have the extent of excursion that
the hock joint in the present study did. The total joint excursions of stifles and hip joints in the present study were similar to those of the other study\(^6\), however, the mean hip joint extension in that study\(^5\) was approximately 15° greater, compared with that of the present study. In the frontal plane, the motion patterns for the hock joint were similar, whereas the motion patterns for the stifles and hip joints differed between that study\(^6\) and the present study. In the present study, the stifle joint was abducted approximately 5° at the beginning of the stance phase and then was gradually adducted during the first half of the stance phase, whereas in the other study,\(^6\) the stifle joint was adducted approximately 20° at the beginning of the stance phase and was slightly abducted throughout the stance phase. Details regarding the placement of the tracking markers were not provided for that study\(^6\); however, if an external hip marker was used, it is surprising that the stifle joint at the beginning of the stance phase was so much more abducted in that study\(^6\) compared with that of the present study. Differences in the results between that study\(^6\) and the present study might be attributable to marker placement and the use of different joint centers for measurement of joint angles. Definition of the joint centers is dependent on the placement of the anatomic markers, and even small variations in the location of the anatomic markers can cause a shift in the initial joint angles. In both the present and that other study\(^6\), the hip joint angle in the frontal plane was abducted by approximately 10° during the stance phase; however, at the beginning of the stance phase, the hip joint angle for the dogs of that other study\(^6\) was abducted approximately 15° more than that for the dogs of the present study. In the transverse plane, the hock joints for the dogs of the present study were rotated internally approximately 15° at the beginning of the stance phase and underwent external rotation throughout the remainder of the stance phase, whereas the hock joints for the dogs of the other study\(^6\) were rotated externally approximately 10° at the beginning of the stance phase and underwent internal rotation during the first half and external rotation during the second half of the stance phase. The stifle joints of the dogs in the present study began the stance phase at a neutral angle and then were externally rotated approximately 10° during the remainder of the stance phase, whereas the stifle joints of the dogs in the other study\(^6\) began the stance phase internally rotated, then underwent external rotation following by internal rotation throughout the remainder of the stance phase. In both the present study and the other study,\(^6\) the slight internal rotation of the hip joint in the transverse plane during the stance phase was similar.

Differences between joint angle and kinetic measurements of the dogs of the present study and those of other studies might be attributed to the fact that the variables of the present study were derived from the true center of each joint. In other studies,\(^12,14,15\) inverse dynamics were used to evaluate the canine pelvic limb only in the sagittal plane, and study investigators relied on anatomic markers that were placed on the lateral side of the limb being evaluated without concern for identifying the joint center. In some studies, 3-D evaluation of the canine pelvic limb involved the use of cadavers\(^9\) or invasive bone implants\(^7,8\) to obtain kinematic data. Although investigators of some studies\(^6,9\) did identify joint centers for the stifle and hock joints during collection of kinematic data, they did not attempt to approximate the center of rotation for the hip joint, and it is unknown what effect failure to identify the hip joint center had on the resulting measurements.

To our knowledge, the present study is the first to describe an approximation of the hip joint center and the use of a virtual marker to identify it during collection of kinematic data. We believe that use of this technique to measure kinematic data is accurate and should be encouraged in future studies conducted to evaluate 3-D biomechanical motion of the pelvic limbs of dogs. Although results of joint angles in the sagittal plane obtained from 2-D measurements are similar to those obtained from 3-D measurements,\(^16\) further investigation is necessary to determine whether 2-D measurements are similar to 3-D measurements in which joint centers have been approximated. Differences in results for moment and power between the present study and other studies could also be caused by the fact that, in the present study, the morphometric data used were obtained from dogs of another study\(^12\) and inertia were estimated on the basis of a geometric form created with 3-D software.

Comparison of inverse dynamics results with descriptions of 3-D movements is difficult. Inverse dynamics is a relatively new area of study in veterinary medicine, and standardized methods for data collection must be defined and adopted before meaningful comparisons can be made. Until a reasonable, clinically applicable, and noninvasive method is developed to collect morphometric data from study subjects, comparison of kinetics between different breeds of dogs will remain difficult. Furthermore, for dogs, kinematic data collection methods must be improved to reduce skin motion artifact and better characterize the motion of the segment being evaluated. Researchers that use inverse dynamics to assess motion in humans and horses place clusters of reflective markers in the middle of each segment being evaluated so that if 1 marker is not captured or a collection error is made, the 3-D motion of the segment is still captured by the remaining markers. Also, placement of a cluster of reflective markers over a large muscle mass makes data collection less prone to skin motion artifact, compared with when markers are placed over boney prominences, and data obtained from the cluster may provide a better representation of the underlying skeletal motion. We attempted to use clusters of markers in the present study, but because of the morphometry of the dog, the clusters could not be maintained in place with adequate separation between the markers to avoid the problem of overlapping or hidden markers.

Limitations of the present study included a small sample size, limited equipment availability, lack of morphometric data for the study dogs, and lack of concurrent EMG monitoring. Although only 6 dogs were evaluated in the present study, the waveforms for angular motion, moment, and power in the hip, stifle, and hock joints were consistent among all study dogs and comparable to those in other studies.\(^6,12,14,15\) The avail-
ability of only four 3-D motion-capture video cameras limited collection of data from only 1 side of a dog at a time. We used morphometric data of Labrador Retrievers that were not specific for the hound-type study dogs, and it is unknown what effect use of that data had on the results. In other studies,13,17 morphometric data were obtained from cadavers. We chose to not euthanize the dogs of the present study for the purpose of obtaining specific morphometric data because morphometric data12 for similarly sized (Labrador Retrievers) dogs were available. A noninvasive CT-dependent method for collection of morphometric data in species of veterinary interest has been developed18 and might eventually be incorporated into methods for collection of subject-specific inverse dynamics data in a clinical setting. Currently, however, this technique is expensive and time-consuming. Consequently, morphometric data need to be extrapolated from currently available databases until further investigation is conducted to catalog breed-specific morphometrics or inexpensive, noninvasive, and clinically relevant methods are developed to collect that data. Regardless, although the accuracy of the results for moment and power in the present study may be affected by the use of historical morphometric data, the findings should be proportional for dogs with similar body types. Electromyography was not used in the present study. The use of EMG would have helped elucidate the patterns and timing of muscle contractions in the pelvic limb. Without EMG data, only the net moments across the joints can be summarized; information regarding which specific muscles contracted to produce those moments is unavailable. Similar to inverse dynamics, the use of EMG in veterinary medicine is relatively new, and investigators of only a couple of studies19,20 have used EMG to monitor pelvic limb muscle activity in dogs. Additional research regarding the use of EMG in dogs is needed to refine and develop standardized protocols before it becomes a routine part of biomechanical analyses of veterinary species. It is unlikely that EMG data would have provided specific information regarding the strength of muscle contraction in the present study. Electromyography might have provided information about the timing of muscle contraction patterns and, at best, a semi-quantitative indication of the strength of contraction of the local muscle mass in the area of the electrode rather than for the entire muscle.

In the present study, inverse dynamics were used to analyze the 3-D movement of the hock, stifle, and hip joints of clinically normal dogs. A novel method to collect kinematic data by means of a static calibration and identification of the approximate center of rotation for the joints evaluated was described. To our knowledge, this study is the first to describe a method for approximating the center of rotation for the canine hip joint and use of a virtual marker to identify that joint center during kinematic data collection. The methods described in this study are important for the production of accurate 3-D kinematic data for evaluation of canine gait patterns by means of inverse dynamics. In human medicine, the use of inverse dynamics to evaluate various joints has provided vast information about the adaption of gait to compensate for injury, lesions, or anatomic asymmetry. Understanding muscle activity across both clinically normal and abnormal joints and subsequent gait adaptations is important so that appropriate treatment can be applied to avoid injury in healthy joints and reduce the progression of further pathology in abnormal joints. The methods described in this study can be extrapolated to the forelimb joints as well as to dogs with abnormal gaits to aid in the evaluation and treatment of joint injuries.

References


