Evaluation of gait-related variables in lean and obese dogs at a trot

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Objective—To assess differences in sagittal plane joint kinematics and ground reaction forces between lean and obese adult dogs of similar sizes at 2 trotting velocities.

Animals—16 adult dogs.

Procedures—Dogs with body condition score (BCS) of 8 or 9 (obese dogs; n = 8) and dogs with BCS of 4 or 5 (lean dogs; 8) on a 9-point scale were evaluated. Sagittal plane joint kinematic and ground reaction force data were obtained from dogs trotting at 1.8 and 2.5 m/s with a 3-D motion capture system, a force platform, and 12 infrared markers placed on bony landmarks.

Results—Mean stride lengths for forelimbs and hind limbs at both velocities were shorter in obese than in lean dogs. Stance phase range of motion (ROM) was greater in obese dogs than in lean dogs for shoulder (28.2° vs 20.6°), elbow (23.6° vs 16.4°), hip (27.2° vs 22.9°), and tarsal (38.9° vs 27.9°) joints at both velocities. Swing phase ROM was greater in obese dogs than in lean dogs for elbow (61.2° vs 53.7°) and hip (34.4° vs 29.8°) joints. Increased velocity was associated with increased stance ROM in elbow joints and increased stance and swing ROM in hip joints of obese dogs. Obese dogs exerted greater peak vertical and horizontal ground reaction forces than did lean dogs. Body mass and peak vertical ground reaction force were significantly correlated.

Conclusions and Clinical Relevance—Greater ROM detected during the stance phase and greater ground reaction forces in the gait of obese dogs, compared with lean dogs, may cause greater compressive forces within joints and could influence the development of osteoarthritis. (Am J Vet Res 2013;74:757–762)

Obesity is the most common nutrition-related problem in dogs.1,2 Recent reports3,4 have described a high prevalence of obesity in dogs and cats. Approximately 50% of dogs are overweight, and approximately 20% are obese.3,5–7 Although there is no objective measure for obesity that is readily available to the general population, dogs with body weight 15% to 20% or more above ideal weight5 can be assessed as obese, and obesity can be determined by use of a body composition scale such as the 9-point BCS system developed by researchers at Purina, which relies on physical examination, palpation, and a visual aid chart.8 Certain breeds such as Labrador Retrievers and Beagles seem predisposed to obesity,9 although obesity can develop in any purebred or mixed-breed dog.

Negative health effects associated with obesity include increased incidence and progression rate of osteoarthritis, reduced cardiopulmonary function, diabetes mellitus, and premature death.10,11 Obesity has also been positively correlated with degenerative joint disease in canine elbow and hip joints.3 Investigators of a 2010 study12 estimated that approximately 20% of adult dogs have osteoarthritis and approximately 25% of adult dogs are obese. Canine obesity may lead to osteoarthritis through increased mechanical loading on joint surfaces during locomotion, as has been shown in humans.13,14 Obesity has been shown to alter gait kinematics in humans by reducing stride length, gait velocity, and ROM in joints of the lower extremities.15–16 Obese humans have larger ground reaction forces and subsequent internal joint forces, compared with lean humans. That may in part be causative for osteoarthritis.14,17 However, to our knowledge, the effect of obesity

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<td>BCS</td>
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<td>pHGRF</td>
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<td>pVGRF</td>
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on canine gait variables has not been well examined or described.

The purpose of the study reported here was to examine sagittal plane joint kinematics and ground reaction forces in healthy lean and obese dogs at 2 trotting velocities. We hypothesized that obese dogs would ambulate with shorter strides and less ROM (flexion and extension) at joints of the forelimbs and hind limbs, while producing greater ground reaction forces.

Materials and Methods

Animals—Lean (n = 8) and obese (8) dogs were recruited from local dog parks and veterinary clinics. A previously described classification system (scale, 1 to 9, where 1 = emaciated and 9 = grossly obese) was used to determine BCS.† Dogs with a BCS of 4 or 5 were eligible for inclusion in the lean group, and those with a BCS of 8 or 9 were eligible for inclusion in the obese group. Other inclusion criteria included being between 18 and 60 months of age, being up-to-date on rabies vaccination, and having no known history of orthopedic injury nor any known degenerative joint disease or lameness as determined on the basis of patient history and physical and orthopedic examinations. Dogs of small (height, < 20 cm) or giant (height, > 40 cm) stature and dogs with chondrodystrophic or chondrodysplastic limb conformation were excluded. Height was defined as the length of the forelimb from the fifth digital pad to the proximal aspect of the olecranon process. All procedures and protocols were approved by the East Carolina University Institutional Animal Care and Use Committee. Institutional review board approval was obtained before any testing occurred. Owners signed university-approved informed-consent forms and provided proof of current rabies vaccination before testing was performed.

Protocol—Dogs were allotted a 5-minute acclimation period, during which they were allowed to walk around the room and become accustomed to the surroundings. Body mass, length, height, and girth were recorded. Length was defined as the length from the base of the skull to the base of the tail and girth as the abdominal circumference at the level of the umbilicus. Height was determined as described for study enrollment criteria. Dogs were then fitted with 12 infrared reflective markers. The fur was parted, and markers were placed on the external occipital protuberance, the dorsal spinous process of T13, the right forelimb (cranial angle of the right scapula, lateral surface of the greater tubercle, lateral humeral epicondyke, ulnar styloid process, and lateral aspect of the head of the fifth metacarpal bone), the cranial dorsal aspect of the iliac spine, and the right hind limb (greater trochanter, lateral femoral epicondyke, lateral malleolus, and lateral aspect of the head of the fifth metatarsal bone).† Dogs were then allotted another 5-minute acclimation period to adapt to the presence of the markers.

Three-dimensional gait kinematics were captured at 120 Hz with an 8-camera motion capture system, and ground reaction force data at 960 Hz were obtained with a force platform. The force platform was located in the center of a 30-m-long walkway and recessed with the walking surface. Ten acceptable trials per dog were recorded at both slow (1.8 ± 0.2 m/s) and fast (2.5 ± 0.2 m/s) trotting velocities. A trial was considered acceptable if the right forefoot and right hind foot struck the force platform solely, without noticeable changes in gait such as stretching, stutter stepping, targetting the plate, or other gait alterations. One handler (RBB) led dogs. Velocity and acceleration were tracked with the marker placed on the dorsal spinous process of T13.

Analysis—Linear positions of the 3-D coordinates for each marker were digitally filtered at 6 Hz with a second-order, low-pass Butterworth digital filter to remove high-frequency error. Sagittal plane angular positions were then calculated for the shoulder, elbow, carpal, hip, stifle, and hock (tarsal) joints. Calculations included peak flexion and extension positions, ROM (defined as the difference between peak extension and flexion angles), and angular velocities at each trotting velocity. Forelimb stride length was calculated from the displacement of the metacarpal marker from paw strike to paw strike.† The pVGRF and pHGRF were recorded by use of the force platform.

Statistical analysis—Normality of distributions was tested with Shapiro-Wilk tests. Mean age, body mass, length, height, abdominal girth, and BCS for lean and obese dogs were compared via 2-tailed t tests. The 5 most consistent trials from each dog at each trotting velocity were chosen for data processing and statistical analysis. These trials were selected by 1 individual (RBB) on the basis of data quality. Trials were excluded if markers were lost during the trial or if stutter or reaching steps that had not been noticed at the time of data collection was observed during review of the recorded trials. Of the remaining trials, the 5 trials that had the most consistent braking and propulsive horizontal ground reaction forces (indicating that the dog trotted at consistent speed throughout the trial) were chosen. A 2 × 2 repeated-measures ANOVA was used to determine group, velocity, and interaction effects within each condition. Differences between groups means (x and y) were calculated as (x – y)/(x + y)/2. Correlation between body mass and pVGRF was assessed. Values of P < 0.05 were considered significant.

Results

Mean ± SD age, length, and height for lean and obese dogs did not differ significantly (P = 0.215, 0.520, and 0.649, respectively; Table 1). Obese dogs had greater body mass (P = 0.029), larger abdominal girth (P = 0.005), and higher BCS (P < 0.001) than did lean dogs.

When trotting at 1.8 m/s, mean forelimb and hind limb stride lengths were 0.94 ± 0.05 m and 0.92 ± 0.03 m, respectively, for lean dogs and 0.88 ± 0.06 m and 0.87 ± 0.07 m, respectively, for obese dogs. When trotting at 2.5 m/s, mean forelimb and hind limb stride lengths were 1.11 ± 0.06 m and 1.10 ± 0.05 m, respectively, for lean dogs and 1.02 ± 0.06 m and 1.02 ± 0.07 m, respectively, for obese dogs. Forelimb and hind limb stride lengths at both velocities were approximately 8% shorter in obese dogs than in lean dogs (P = 0.022 and P = 0.039, respectively).
Mean joint angles of a single stride for lean and obese dogs were summarized graphically (Figure 1). During the stance phase, when trotting at 1.8 m/s, mean shoulder joint flexion was smaller and mean elbow, hip, and tarsal joint extension were greater in obese dogs, compared with lean dogs, whereas at 2.5 m/s, mean shoulder, elbow, and tarsal joint flexion were smaller and mean hip joint extension was greater in obese dogs, compared with lean dogs (P < 0.05 for all comparisons; Table 2). During the swing phase, when trotting at 1.8 m/s, mean elbow joint flexion was smaller and mean elbow and hip joint extension were greater in obese dogs, compared with lean dogs, whereas at 2.5 m/s, mean elbow and hip joint flexion were smaller in obese dogs, compared with values for lean dogs (P < 0.050).

During the stance phase, ROM was greater in obese dogs than in lean dogs at both velocities for the shoulder (28.2° vs 20.6° [29% difference]; P = 0.005), elbow (23.6° vs 16.4° [44% difference]; P = 0.004), hip (27.2° vs 22.9° [17% difference]; P = 0.005), and tarsal (38.9° vs 27.9° [33% difference]; P = 0.012) joints. During the swing phase, ROM was greater in obese dogs than in lean dogs for the elbow (61.2° vs 53.7° [14% difference]; P = 0.029) and hip (34.4° vs 29.8° [14% difference]; P = 0.033) joints. Increased velocity was associated with increased stance phase ROM for the elbow joint in obese dogs (P = 0.010) and increased stance and swing phase ROM in the hip joint for obese dogs (P < 0.001 and 0.016, respectively). Velocity influenced tarsal joint ROM differently in lean and obese dogs (P = 0.032 for interaction effect); lean dogs had a decrease in tarsal joint ROM with increased velocity during the stance phase, whereas obese dogs did not. Increased velocity did not influence ROM of the shoulder, carpal, or stifle joints.

Obese dogs exerted greater pVGRF on their forelimbs (329 N vs 256 N [25% difference]; P = 0.033) and hind limbs (222 N vs 177 N [26% difference]; P = 0.008) at both velocities than did lean dogs (Table 3). Increased velocity was associated with increased pVGRF in forelimbs (300 N vs 284 N; P = 0.025) but not in hind limbs (200 N vs 191 N; P = 0.187) for all dogs. Obese dogs exerted greater propulsive pHGRF on their forelimbs (28 N vs 18 N [47% difference]) and hind limbs (25 N vs 17 N [41% difference]) at both velocities (P = 0.003) than did lean dogs. Obese dogs exerted greater braking pHGRF on their forelimbs (–40 N vs –30 N [28% difference]) and hind limbs (–13 N vs –8 N [46% difference]) at both velocities (P = 0.009) than did lean dogs. Increased velocity was associated

<table>
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<tr>
<th>Group</th>
<th>Age (mo)</th>
<th>Body mass (kg)</th>
<th>Length (cm)</th>
<th>Height (cm)</th>
<th>Abdominal girth (cm)</th>
<th>BCS</th>
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<tr>
<td>Lean</td>
<td>30.6 ± 17.7a</td>
<td>24.0 ± 5.4a</td>
<td>75.7 ± 8.6a</td>
<td>30.2 ± 2.0a</td>
<td>53.6 ± 5.6a</td>
<td>4.4 ± 0.5a</td>
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<tr>
<td>Obese</td>
<td>41.0 ± 13.9a</td>
<td>32.2 ± 7.8a</td>
<td>73.0 ± 9.7a</td>
<td>29.5 ± 3.3a</td>
<td>71.4 ± 12.9a</td>
<td>8.5 ± 0.8a</td>
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A previously described classification system (scale, 1 to 9, where 1 = emaciated and 9 = grossly obese) was used to determine BCS.1 Dogs in the lean group had a BCS of 4 or 5, and those in the obese group had a BCS of 8 or 9.

Within a column, values with different superscript letters are significantly (P < 0.05) different.

Figure 1—Mean joint angles of a stride for lean (n = 8; black line) and obese dogs (8; gray line) in a study to evaluate differences in sagittal plane joint kinematics and ground reaction forces between groups at a trot. Solid lines indicate stance phase measurements. Dashed lines indicate swing phase measurements.
Table 2—Mean ± SD kinetic variables (*) for the same 16 dogs as in Table 1 trotting at 2 different velocities.

| Variable | 1.8 m/s | | | 2.5 m/s | | |
|----------|---------|---------|------|---------|---------|
|          | Lean dogs | Obese dogs | Lean dogs | Obese dogs | Lean dogs | Obese dogs |
| Stance   | Swing    | Stance   | Swing    | Stance   | Swing    |
| Shoulder joint | Flexion | 123 ± 12 | 123 ± 12 | 120 ± 12 | 116 ± 13 |
|            | Extension | 153 ± 12 | 151 ± 12 | 157 ± 11 | 154 ± 13 |
|            | ROM      | 20.3 ± 3.3 | 29.3 ± 5.9* | 37.9 ± 11.7 | 38.1 ± 7.4 |
| Elbow joint | Flexion | 130 ± 9 | 133 ± 9 | 95 ± 7 | 90 ± 11 |
|            | Extension | 145 ± 9 | 155 ± 9 | 147 ± 17 | 151 ± 9 |
|            | ROM      | 15.4 ± 4.6 | 22.4 ± 5.4* | 52.5 ± 25 | 60.0 ± 9.7* |
| Carpal joint | Flexion | 178 ± 10 | 172 ± 17 | 96 ± 36 | 92 ± 17 |
|            | Extension | 212 ± 10 | 211 ± 20 | 203 ± 19 | 209 ± 18 |
|            | ROM      | 34.5 ± 4.0 | 38.4 ± 12.2 | 106.8 ± 23.8 | 114.8 ± 14.0 |
| Hip joint  | Flexion  | 111 ± 9 | 114 ± 11 | 108 ± 7 | 107 ± 12 |
|            | Extension | 132 ± 10 | 139 ± 11 | 136 ± 9 | 139 ± 15 |
|            | ROM      | 211 ± 2.9 | 25.1 ± 3.8* | 28.4 ± 4.7 | 32.8 ± 4.5* |
| Stifle joint | Flexion | 127 ± 9 | 119 ± 13 | 91 ± 18 | 83 ± 13 |
|            | Extension | 142 ± 8 | 136 ± 12 | 145 ± 10 | 141 ± 13 |
|            | ROM      | 14.9 ± 3.9 | 16.9 ± 2.5 | 53.9 ± 12.7 | 57.5 ± 16.1 |
| Tarsal joint | Flexion | 121 ± 13 | 118 ± 12 | 109 ± 37 | 99 ± 12 |
|            | Extension | 150 ± 10 | 158 ± 8 | 155 ± 9 | 158 ± 9 |
|            | ROM      | 29.0 ± 6.1 | 38.0 ± 8.2* | 45.8 ± 9.9 | 55.9 ± 11.1 |

| Flexion and extension are mean peak (maximal) values. Values were calculated from gait kinematic data obtained at 120 Hz with an 8-camera motion capture system and 12 infrared markers placed on bony landmarks. Measurements from the 5 most consistent trials for each dog were used in analyses. *Within a phase, ROM for the joint was greater at a given velocity for obese dogs than lean dogs (P < 0.05). †Within a phase, ROM was significantly (P < 0.05) decreased at 2.5 m/s, compared with the value for the same group at 1.8 m/s. ‡Within a phase, ROM was significantly (P < 0.05) increased at 2.5 m/s, compared with the value for the same group at 1.8 m/s.

with increased propulsive pHGRF in hind limbs (23 N vs 19 N; P = 0.010) but not in forelimbs (23 N vs 21 N; P = 0.634) for all dogs. Similarly, increased velocity was associated with increased braking pHGRF in hind limbs (–12 N vs –8 N; P < 0.001) but not in forelimbs (–38 N vs –33 N; P = 0.116) for all dogs.

Significant (P < 0.001 for all) correlations between body mass and pVGRF were detected for the forelimb (r = 0.92) and the hind limb (r = 0.88) in dogs trotting at 1.8 m/s and for the forelimb (r = 0.92) and the hind limb (r = 0.84) in dogs trotting at 2.5 m/s.

**Discussion**

The effects of obesity on gait in dogs have not been described, to our knowledge. In the present study, we compared gait-related variables in obese and lean dogs of similar sizes (height and length). Our findings clearly show that obesity influences the gait of dogs. We accepted the hypothesis that pVGRF would be greater in obese dogs, compared with that in lean dogs. The pVGRF was positively correlated with body mass. Obesity also leads to increased pVGRF in humans.3 Given that joint surfaces were probably similar between groups, in our opinion, the larger ground and joint forces in obese dogs likely resulted in larger stresses on joint surfaces in obese dogs, compared with lean dogs.

We also accepted the hypothesis that obese dogs would have shorter strides, compared with lean dogs. A smaller stride length probably represents an adaptive change toward optimizing locomotion in obese dogs. Obese humans walk with shorter strides, compared with lean humans.16 Shorter strides in humans are associated with smaller joint loads10 and greater shock absorption.12 Another protective strategy in obese individuals is to walk more slowly.20 Whether obese dogs adapt their speed to minimize joint loads could not be assessed in the present study because dogs did not move at their own preferred pace.
We rejected the hypothesis that obese dogs would ambulate with smaller ROM, compared with lean dogs. Rather, obese dogs trotted with greater stance phase ROM in shoulder, elbow, hip, and tarsal joints. The greater ROM measurement resulted from greater flexion or extension, depending on joints and velocity. The greater ROM in multiple joints in obese dogs in the present study was apparently counterproductive and not consistent with the results of studies in obese humans, where ROM in the knee joint is less than that of lean subjects. A smaller ROM is seemingly an adaptive mechanism that protects the joints of heavy individuals from higher loads, greater torque, and greater shear forces that occur when larger body mass is combined with greater ROM. Muscle forces are a key factor in total knee loads, and small changes in walking kinematics in humans (eg, knee joint flexion angle) have a substantial effect on the magnitude of knee joint forces. The increase in muscle force required during locomotion with increased flexion has been confirmed analytically. In humans, moderate obesity is associated with greater torque on the knee joint while walking, which suggests greater loads on the knee joint, whereas morbid obesity is associated with shorter strides, a lesser degree of knee joint flexion, and smaller amounts of knee joint extensor torque relative to weight at the same gait. Shorter strides and less knee joint flexion shorten the external lever arm of the pVGRF and therefore decrease muscle force and torque and knee joint loading.

The greater ROM detected in obese dogs at a trot in the study reported here is not a feature present in larger and heavier quadrupeds. Elephants, which have been described as having energy-saving locomotion, walk with a ROM no larger than that reported for lean dogs. The reason the locomotion of obese dogs differed so much from that of lean dogs in our study is unclear. We suspect that canine limbs are more compliant than human lower limbs during the stance phase because dogs have limb segments that are more horizontally oriented when the foot contacts the ground while trotting, compared with the posture of humans. Dogs therefore support themselves more with muscular effort and less with skeletal segments than do humans, an inherently less stiff mechanism. The more horizontal orientation creates larger lever arms for the ground reaction forces than more vertically oriented limbs, thus increasing the degree of external torque at dogs’ joints. Obese dogs that have larger GRFs, compared with lean dogs, may not have the muscular strength to resist the flexing action resulting from larger amounts of external torque. This apparent lack of gait adaptation could be also linked to the shapes of joint surfaces in dogs, the ratio of structural joint volume to body mass, muscle function, or other factors. The greater ROM found in obese dogs of the present study, together with their greater body mass when compared with lean dogs, requires greater muscle torque production around the joint, increasing joint moment arms (distance from the ground reaction force vector to the centers of rotation of joints) and shear and compressive forces within joints. The increase in moments and forces could be a contributing factor to the more rapid progression of osteoarthritis in obese dogs, compared with lean dogs, particularly for joints with intrinsic laxity, where subluxation could be exacerbated by greater ground reaction forces and ROM. In a long-term clinical study comparing radiographic signs of osteoarthritis in overweight and lean canine siblings, joints with intrinsic laxity (the hip and shoulder) had a dramatic increase in prevalence of osteoarthritis, but joints without intrinsic laxity (the elbow) had no increase in prevalence of osteoarthritis over time. In the present study, changes in ROM at the tarsus were dissimilar between obese and lean dogs when velocity was increased: stance phase tarsal joint ROM decreased in lean dogs but not in obese dogs. The decrease detected in tarsal joint ROM at 2.5 m/s in lean dogs was most likely attributable to an increase in muscle stiffness that may aid in springing forward. This response was not observed in obese dogs. Further research could assess the nature and amplitude of forces present in the joints of obese dogs and could potentially develop compensatory strategies to offset force abnormalities. In humans, training has been shown to improve the gait of obese individuals that have a stiff-kneed gait.

In the present study, skin-mounted reflective markers were used to determine joint motion in a sagittal plane. We placed markers on a single side of the dogs because we assumed that the trot was symmetric, as previously reported, and we did not intend to assess gait symmetry. Skin motion relative to joints during a gait, described as skin movement artifacts, has been evaluated in humans, dogs, and rats. In humans, skin movement artifacts in the sagittal plane are small, relative to total movement. In dogs and rats, skin movement artifacts influence measurements of hip and stifl joint motion. Similar surface marker attachment methods were used in obese and lean dogs in this study. Therefore, skin movement artifacts in both groups were likely comparable and were both attenuated by the use of a Butterworth filter. However, it is possible that skin motion while trotting is larger in obese dogs than in lean dogs because heavier skin and subcutaneous tissues in obese dogs may have more inertia at the end of the swing phase.

We concluded that obesity influences gait-related variables in dogs. Obesity was associated with greater pVGRF and pHGRF; greater ROM at the shoulder, elbow, hip, and hock joints during stance phase; and shorter stride length when compared with values for lean dogs. Further research could investigate the magnitude of joint forces in obese dogs, compared with lean dogs, and the impact of these changes on osteoarthritic joints in addition to exploring gait-training strategies to address gait abnormalities.

c. Visual3D, C-Motion Research Biometrics, Germantown, Md.
d. IBM SPSS, version 19, IBM, New York, NY.
References


