Three-Dimensional Kinematic Gait Analysis of Doberman Pinschers with and without Cervical Spondylomyelopathy

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Abstract

Background—The optimal treatment of cervical spondylomyelopathy (CSM) is controversial, with the owner's and clinician's perception of gait improvement often being used as outcome measures. These methods are subjective and suffer from observer bias.

Objectives—To establish kinematic gait parameters utilizing digital motion capture in normal Doberman Pinschers and compare them with CSM-affected Dobermans.

Animals—Nineteen Doberman Pinschers; 10 clinically normal and 9 with CSM.

Methods—All dogs were enrolled prospectively and fitted with a Lycra® body suit, and motion capture was performed and used to reconstruct a 3-D stick diagram representation of each dog based on 32 reflective markers, from which several parameters were measured. These included stride duration, length, and height; maximal and minimal spinal angles; elbow and stifle flexion and extension; and maximum and minimum distances between the thoracic and pelvic limbs. A random-effects linear regression model was used to compare parameters between groups.

Results—Significant differences between groups included smaller minimum (mean = 116 mm; P = .024) and maximum (mean = 184 mm; P = .001) distance between the thoracic limbs in CSM-affected dogs. Additionally, thoracic limb stride duration was also smaller (P = .009) in CSM-affected dogs (mean = 0.7 seconds) when compared with normal dogs (mean = 0.8 seconds). In the pelvic limbs, the average stifle flexion (mean = 100°; P = .048) and extension (mean = 136°; P = .009), as well as number of strides (mean = 2.7 strides; P = .033) were different between groups.

Conclusions and Clinical Importance—Our findings suggest that computerized gait analysis reveals more consistent kinematic differences in the thoracic limbs, which can be used as future objective outcome measures.

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Keywords

Cervical instability; Digital motion capture; Dog; Wobbler

Kinematic gait analysis quantifies the positions, velocities, accelerations, and angles of anatomic landmarks, segments, and joints in space.[1] This technique has been used to recognize and characterize clinically normal gait patterns and identify abnormal gait patterns related to pathologic conditions in humans, dogs, and horses.[2-4] Kinematic gait analysis is also a valuable, objective outcome measure in models of spinal cord injury in rodents,[5,6] and has recently been reported as a method for determining forelimb– hindlimb coordination in spinal cord injured dogs.[7,8] These studies in dogs and rodents have utilized digital motion capture to evaluate the gait after thoracolumbar spinal cord injury.

Cervical spondylomyelopathy (CSM), also known as wobbler syndrome, is one of the most common diseases of the cervical spine in large and giant breed dogs, particularly in Doberman Pinschers.[9] The disease is secondary to a collection of disorders affecting the caudal cervical vertebrae and intervertebral disks resulting in clinical signs of spinal cord compression, nerve root compression, or both, including neurologic deficits, cervical hyperesthesia, or both.[10,11] Gait abnormalities are often one of the first noted signs in dogs with CSM and are observed as a slowly progressive hind limb ataxia or "wobbling" of the pelvic limbs.[9,12] Additionally, thoracic limb abnormalities may manifest themselves as varying degrees of ataxia in combination with a short, stilted gait.[9,13] Treatment options for CSM include conservative management or surgical decompression; however, the best option for treatment is still highly controversial.[9,14] Herein lies the need to develop better methods for assessing a patient's response to treatment as outcome measures for CSM reported thus far are highly inconsistent.[9] Currently, treatment outcomes for dogs with CSM are based on subjective parameters such as the owner's and clinician's perception of improvement based on gait and neurologic examination findings. In addition to being subjective, these parameters are dependent on observers' experience and can be biased. Thus, the need to develop a more reliable and objective means of assessing a patients' response to treatment.

The purpose of this study was to prospectively utilize digital video motion capture to compare multiple kinematic parameters of the trunk, thoracic, and pelvic limbs in Doberman Pinscher dogs with and without CSM. We hypothesized that a subset of the parameters, including thoracic and pelvic limb stride length, elbow joint flexion and extension, and truncal sway (ie, spinal angles), would be significantly different between normal and CSM-affected Doberman Pinscher dogs. The identification of consistent differences in kinematic parameters between normal and CSM-affected dogs could serve as the initial step in the development of objective outcome measures for dogs with CSM.

Materials and Methods

Animals

Nineteen client-owned mature Doberman Pinscher dogs were prospectively enrolled in this investigation from August 2010 through September 2011. The study was conducted in

accordance with the guidelines and with approval of the Clinical Research Advisory Committee and the Institutional Animal Care and Use Committee of The Ohio State University. Written owner consent was obtained before study enrollment.

Normal Dogs

Dogs were considered clinically normal and eligible for study enrollment if they were greater than or equal to 1 year of age, in addition to no abnormalities identified on physical, orthopedic, and neurologic examination. Additionally, their history could not reveal any previous previous orthopedic or neurologic disease.

Affected Dogs

Dogs were considered affected and eligible for study enrollment if they had neurologic examination findings consistent with a cervical myelopathy and were skeletally mature (1 year of age). All affected dogs underwent physical and neurologic examinations performed by two of the authors (KF, RdC), complete blood count, biochemistry profile, cervical spinal radiographs, and magnetic resonance imaging (MRI) examination of the cervical spine. Neurologic status at the time of initial examination was graded on a scale from 1 to 5 on the basis of a previously published grading scale.[10,15] Dogs classified as Grade 1 were those with cervical hyperesthesia only. These dogs were excluded from participation. Grade 2 dogs were those with mild pelvic limb ataxia or paresis with mild thoracic limb involvement. Thoracic limb involvement was defined as either a short-strided or spastic gait with a floating appearance. Grade 3 dogs were defined as having moderate pelvic limb ataxia or paresis with thoracic limb involvement as described in Grade 2. Grade 4 was defined as marked pelvic limb ataxia or paresis with thoracic limb involvement, and Grade 5 was defined as nonambulatory tetraparesis. Any dog with Grade 5 neurologic status was also excluded from the study. The diagnosis of CSM was confirmed in all dogs with MRI, utilizing a modified standard protocol,[10] to support evidence of spinal cord compression with or without spinal cord signal change. Before general anesthesia for the MRI, a minimum database consisting of a CBC and chemistry profile was performed in all dogs. Additionally, thoracic radiographs were performed in all affected dogs >7 years of age (n = 5).

Equipment Setup

Fifteen red LED motion capture cameras with a recording frequency of 120 frames per second were positioned around a designated capture space ($24' \times 24'$), using the Vicon8i motion capture system, and were calibrated to permit recording from all positions (Figs 1, 2). We defined the sagittal plane (viewing the dog from the side) as the *x*-plane, the vertical plane as the *y*-plane, and movement toward/forward and away/backward, as the *z*-plane in all dogs except for three of the normal dogs. Thirty-two reflective markers were attached to a Lycra® body suit and wrist bands overlying specific anatomical landmarks depicted on Figure 1. Each marker was placed at least 4 cm apart to avoid interference with the LED camera recording.

Recording

Dogs were acclimated to the Lycra® suit, the handler, and the capture space for approximately 10–15 minutes before marker attachment. All dogs were walked at a slow pace (approximately 0.7–0.8 m/s), maintaining a consistent gait and pace along a horizontal line in the capture space. Anytime a dog shook, stopped walking, or was not walking as straight as possible, this pass was excluded from the data. Each horizontal pass providing approximately 10 seconds of valid motion capture. All valid passes were then added together until a total of 45–90 seconds of motion capture data were acquired.

Data Analysis

Processing of the recorded images was carried out with Vicon iQ 2.0 software.[a] The 32 individual markers were identified and labeled to reconstruct a 3D stick diagram representation of each dog (Fig 2). Visual examination of lateral and forward movement was displayed in the Vicon iQ 2.0 graphical plots of the *z*-plane and *x*-plane and was used to exclude any sections of data in which a dog was not walking consistently (either abrupt stopping, shaking, or drifting to one side or the other). Before beginning data collection, a standing pose was performed in the *x*-plane allowing visualization of all 32 markers. Analysis of coordination was focused on data obtained from the paws and from the spine. Positional data, such as stride height, for all paws were determined in the *x*- and *z*- plane, limb angles determined in the *x*-plane, spine angle from the *y*-plane, limb distance in the *z*-plane, and step cycle duration and stride length in the *x*-plane (Fig 1).

Parameters recorded in all dogs were step cycle duration, stride length, stride height, number of strides from each limb, truncal sway, elbow and stifle flexion, elbow and stifle extension and maximum and minimum distance between contralateral limbs (thoracic and pelvic limbs). Step cycle duration was calculated using each individual paw by measuring the time elapsed between one maximal *x*-plane position and the next. Stride length was calculated for each individual limb using each foot in the *x*-plane by measuring the distance in mm from one maximal position to the next. Stride height was determined by the estimated maximum distance between each individual foot and the floor in the *x*-plane.[6] The number of strides was recorded from each limb of every dog and counted as successive maximal *x*-plane positions. Truncal sway was calculated based on the maximal and minimal lateral deviation of the spine at any given time during the walking phase. Two vectors were established, Vector v1 from cneck2 to spine1, and Vector v2 from cneck2 to spine4. The maximum and minimal angles were the angles made between these two vectors in the *y*-plane (Fig 3—top). Lastly, the joint angle of the elbow and stifle joints was determined by the maximum joint angle positions in both flexion and extension and measuring the maximum and minimum values for each angle during the step cycle.[6] Joint angle for the elbow joint was based on the angle made between the markers in the *x*-plane located at the humeral head, the elbow, and fore paw (Fig 3— bottom). Stifle angles were defined as the maximum and minimum angle formed by the greater trochanter, the stifle joint, and the tarsal joint (Fig 3—bottom). Maximum and minimum distance between the thoracic and pelvic limbs was the maximum and minimum distance recorded between the contralateral limbs in the *z*-plane.

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[a]Vicon, Los Angeles, CA

Statistical Analysis

All data were cleaned and exported using Microsoft® Visual Studio 2009.[b] All data acquired in Vicon iQ 2.0 were then transferred as numerical data into Matlab.[c] A custom-written script was used to extract the data points of interest. The resulting data were then analyzed by Stata 12.0.[d] Repeated observations within a dog were considered a technical replicate and were averaged over the number of observations. This average was the estimate of each measurement within a particular dog. Differences in means were tested by a random-effects linear regression model as both the left and right side observations were considered to be nested within a dog. For observations that were not associated with left or right side (maximum thoracic limb distance or maximum spine angle), the values were not repeated within a dog, and the difference in the means between groups was analyzed by a two-sample *t*-test. Additionally, the coefficient of variation was also calculated for those parameters found to be different between the two groups. Significance level for tests was set at $P < .05$.

Results

A total of 19 dogs were enrolled (10 clinically normal dogs and 9 CSM-affected dogs)The group of normal dogs was comprised of 9 males and 1 female between 1 and 7 years old (mean 4.2 years, SD 1.87, median 4 years) with body weights ranging from 31.3 to 43.6 kg (mean 37.94, SD 4.53, median 39.25 kg). The CSM-affected group included 6 males and 3 females between the ages of 3 and 12 years (mean 7.7 years, SD 3.35, median 9 years). Clinical signs included mild pelvic limb ataxia or paresis with thoracic limbs involvement (Grade 2; n = 4), moderate pelvic limb ataxia or paresis with thoracic limb involvement (Grade 3; n = 2), and marked pelvic limb ataxia or paresis with thoracic limb involvement (Grade 4; n = 3). The body weight of the dogs ranged from 27.2 to 55.8 kg (mean 37.4 kg, SD 6.67, median 35.6 kg). All CSM-affected dogs had spinal cord compression located in the caudal cervical spine as identified by MRI. The main compression was located at C5-6 in 3 dogs, and at C6-7 in 6 dogs. The main cause of spinal cord compression was disk-associated in 8 dogs, with or without ligamentous compression. One dog had bilateral dorsolateral osseous compression.

Kinematic gait analysis was successfully performed in all nineteen dogs. The entire process for each dog ranged from 45 minutes to 3 hours (average time was approximately 1.5 hours), including set-up (application of the Lycra® suits and marker placement), and data collection to obtain a total of 45–90 seconds of adequate motion capture. The normal dogs took approximately 60 minutes on average, with the CSM dogs taking approximately 65 minutes. The difference between groups was minimal and we observed no association between collection time and neurological status. The number of steps from all limbs ranged from 188 to 340 (mean 236.9) in the normal dogs, and from 190 to 343 (mean 256) in the affected dogs. The range and the mean number of steps were not different between groups. Observations for each dog ranged from 8 to 24 (mean 15.3 ± 1.54 SE) in the normal Dobermans and from 13 to 38 (mean 23.4 ± 2.56) in the affected dogs. The variation in

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[b]Microsoft, Redmond, WA
[c]Matlab, Natick, MA
[d]Stata Corporation, College Station, TX

number of observations and amount of motion capture did not appear to be related to the neurologic status of the dog, but seemed to more specifically related to the dog's behavior (ie, willingness to walk in a straight line wearing a suit with markers). The mean value for each kinematic parameter assessed and its associated 95% confidence interval are presented for both the normal and affected dogs in Table 1.

Minimum thoracic limb distance was significantly smaller ($P = .024$) in CSM-affected dogs (mean = 116 mm) versus normal dogs (mean = 146 mm) (Fig 4), as was maximum thoracic limb distance ($P = .001$) with a mean of 184 mm in CSM-affected dogs and 222 mm in normal dogs (Fig 5). Additionally, stride duration in the thoracic limbs was also significantly smaller ($P = .009$) in CSM-affected dogs (mean = 0.7 seconds) when compared with normal dogs (mean = 0.8 seconds), with an effect size using a random-effects linear regression being 0.12 (95% CI: –0.21 to –0.03) lower in the CSM-affected dogs compared with the normal dogs. (Fig 6; also see supplementary videos in the online version). Other values found to be of difference included significantly fewer strides in the pelvic limbs ($P = .033$) of CSM-affected dogs (mean = 2.7 strides) versus normal dogs (mean = 4.7 strides), as well as CSM-affected dogs having smaller average stifle flexion and extension (100 and 136°, respectively) compared with normal dogs (109 and 146°, respectively) ($P = .048$) and significantly smaller average flexion ($P = .023$) and average extension ($P = .005$) from all 4 limbs of CSM-affected (mean = 101 and 137°, respectively) dogs when compared with that of normal dogs (mean = 107 and 146°, respectively).

Discussion

This study uses digital motion capture to identify gait parameters that are altered in CSM-affected Doberman Pinschers as a means of providing more objective outcome measures when evaluating a treatment. Dogs with CSM have a tendency to have shorter thoracic limb stride duration than normal dogs, as well as a smaller distance between the thoracic limbs during the stance phase of the gait. Additionally, the average number of strides in the pelvic limbs of CSM-affected dogs was not only much smaller than that of the pelvic limbs in normal dogs but also smaller when compared with the thoracic limbs within affected dogs as well as normal dogs. Clinically, Doberman Pinschers with CSM can present with what is a characteristic "two-engine" gait. This is observed as a short-strided thoracic limb gait with a wide-based, long-strided pelvic limb gait often giving the appearance that the gait is "disconnected"[9,16] and could explain why CSM-affected dogs tended to have fewer strides in the pelvic limbs versus their thoracic limbs when compared with normal dogs. Normal quadrupedal coordination is defined as for every forelimb step, a hind limb step is taken and the hind limbs alternate with each step.[17,18] Thus, based on this definition, our findings indicate that CSM-affected dogs are incoordinated when compared with healthy Dobermans.

Of interest is the fact that despite the CSM-affected dogs clinically showing various degrees of pelvic limb incoordination, there were no differences detected in stride duration, stride length, or distance between the pelvic limbs. Even though we were not expecting this finding, we are not the first to document it. A study examining spatiotemporal gait characteristics in normal dogs and those with thoracolumbar spinal cord disease also found that the thoracic limbs in the neurologic dogs had significantly shorter stride lengths, shorter

stride durations, and decreased stance times compared with normal dogs,[19] which could also be occurring in dogs with CSM. Additionally, despite the neurologic dogs being ataxic in the pelvic limbs, the study found no differences in stride length, stride duration, or stance time in the pelvic limbs.[19] It is possible that ours and this other study suffer from a common issue with clinical research, which is the variability in the patient population. We tried to minimize this by investigating a single disease process in 1 breed only, yet it is possible that a much larger sample size would be required to demonstrate differences in the pelvic limb parameters. As for the finding of there being no differences in the pelvic limbs, despite some dogs having profound ataxia, our study only compared the mean values from each parameter, not evaluating individual limb differences, in accordance with a previous study.[19] Ataxic patients can have large variability in stride length and foot placement from stride to stride. Therefore, some strides could have been long and others short, but the mean of these values could have eliminated differences.

We anticipated that the pelvic limbs of CSM-affected dogs would also show marked differences in pelvic limbs kinematic parameters compared with normal dogs. In general, the common clinical presentation of CSM is characterized mostly by pelvic limb ataxia, a long-strided pelvic limb gait, and paresis.[9] However, based on the findings of the current study, it would appear that there are also dramatic changes within the thoracic limbs. Most locomotor scoring systems used for assessment of spinal cord injury in dogs assess only the pelvic limbs.[20,21] The gait score used in this study was adapted from a previous study on Doberman Pinschers with CSM[10] with the goal of also taking into account the thoracic limbs. However, this scale and previous scales based on gait evaluation of canines with cervical spine disorders only state whether or not the thoracic limbs are affected, but do not go into any further detail on the degree of thoracic limb abnormalities. [10,22,23] The clinical changes in the thoracic limbs of CSM-affected dogs need therefore to be better characterized. CSM-affected dogs also had decreased range of motion in the stifle joints, as noted by much smaller angles of stifle flexion and extension in this group, which most likely lead to the overall average smaller flexion and extension. These smaller angles could be attributed to the pelvic limb paresis that is often seen with CSM.[9] Additionally, based on the varying severity of pelvic limb ataxia that can be observed, we predicted that CSM-affected dogs would have more truncal sway (larger spinal angles) in comparison with normal dogs, which was not the case in this study. It is unclear why differences were not detected.

Limitations of this study include the fact that while we attempted to keep the dogs moving at a consistent pace, there were no means of monitoring velocity/speed, which may lead to a larger variability in some of the parameters, in particular, stride duration. Other studies in dogs with thoracolumbar lesions chose to maintain constant speed using a treadmill.[7] We chose to walk dogs in a large area without specifically controlling the speed as in a treadmill, because this is typically how the gait examination is performed, and we felt that possibly this would allow us detect more gait differences. It is also unknown what role the Lycra® body suit played in potentially altering the gait of the dogs. While all dogs were given time to acclimate to the suit itself, it could have led to minor gait changes. However, all dogs underwent the analysis wearing the suit so any interference was consistent among all dogs. We chose to use the suit to minimize soft tissue artifact, a concern with kinematic gait analysis. This artifact occurs when markers are placed on the skin to monitor the

movement of underlying skeletal structures noninvasively and has been shown to affect kinematic measurements in horses, in humans, and most recently, in dogs.[24-26] Also, our sample size was small and may not been enough to detect more differences. For example, to detect differences in stride length of approximately 20 mm in the pelvic limbs with an 80% power, we would need 116 dogs (58 per group). Yet for maximum thoracic limb distances, it was found that only 7 dogs were needed per group to detect a difference of 20 mm, thus giving this study adequate power for this parameter. Although large sample sizes are ideal, it is difficult to achieve larger samples sizes in specific funding periods (1–2 years) when dealing with a disease process in a single breed. Additionally, we included 1 dog with dorsolateral osseous compression in the study. We chose to include the dog with dorsolateral osseous compression as there is no indication that the direction of compression affects the spinal cord in different ways. In a recent study, we investigated whether the direction of compression had an effect on spinal cord signal changes and found no relationship. [27] This dog also had mild pelvic limb ataxia (Grade 2), which, we felt, was not any different from the other 3 dogs that were Grade 2 on the gait score with ventral compression.

In summary, the use of 3-D motion capture to evaluate various gait parameters in normal and CSM-affected Doberman Pinschers revealed that the thoracic limb distances and thoracic limb stride duration were significantly smaller in CSM-affected Doberman Pinschers. Additionally, computerized kinematic gait analysis also revealed that CSM-affected Doberman Pinschers have fewer number of strides in the pelvic limbs versus their thoracic limbs, but also fewer pelvic limb strides compared with normal dogs. This finding is suggestive that CSM-affected Doberman Pinschers, by definition, are truly incoordinated in their pelvic limbs. The consistent kinematic differences found on this study will be used to objectively evaluate the treatment response of dogs with CSM.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments

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Abbreviations

CSM   cervical spondylomyelopathy

MRI   magnetic resonance imaging
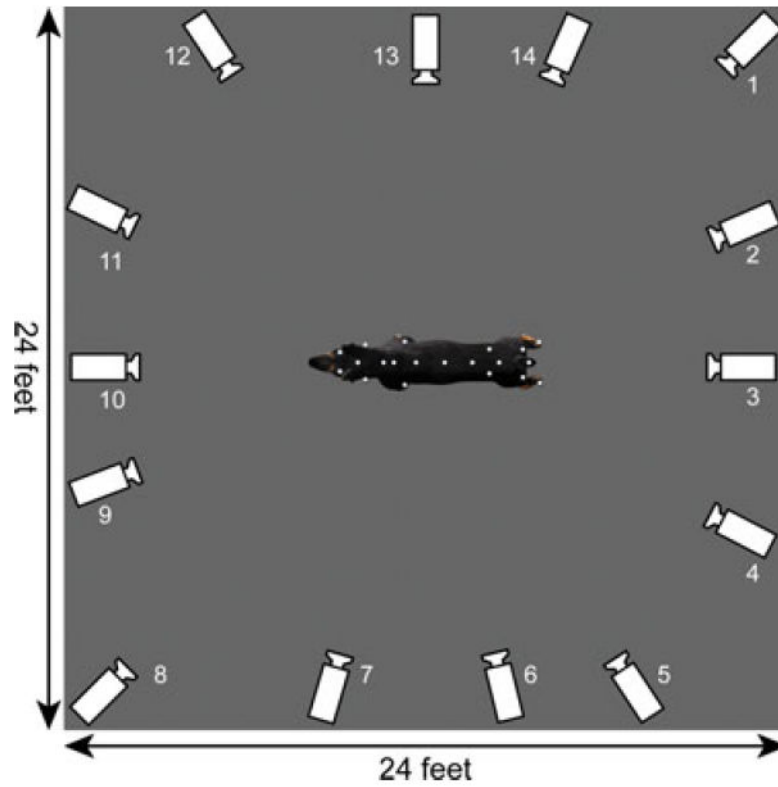
CV   coefficient of variation

Fig 1.
Representation of the motion capture studio showing the dimensions and position of the recording cameras. To facilitate visualization, the image of the dog was magnified in 2.5 times in relation to its actual size.
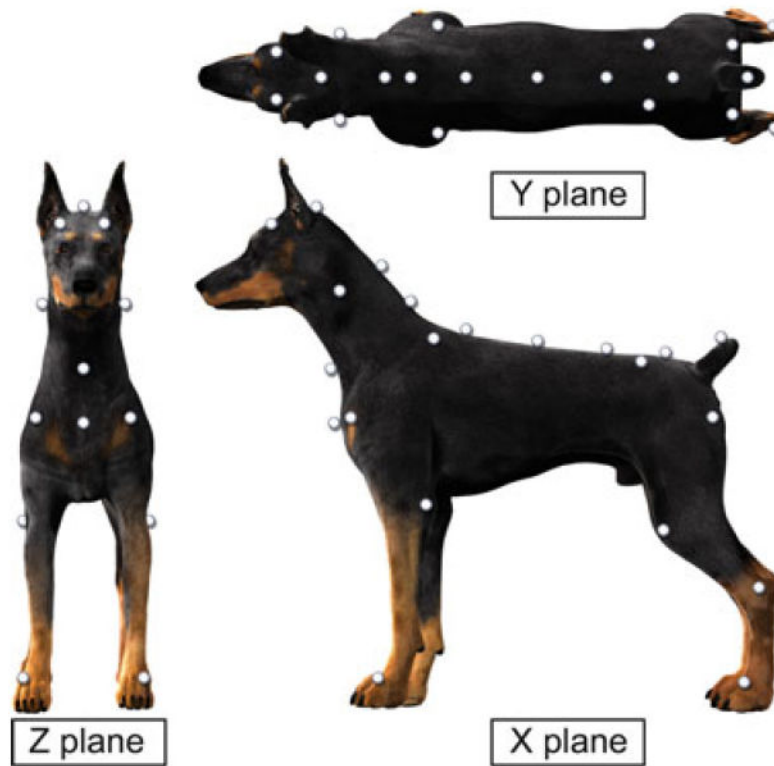
Fig 2.
Digital reconstruction showing anatomic marker placement in the doral, lateral, and frontal plane. Anatomic landmarks represented included the parietal bone, the occipital crest, the spine of the scapula, the head of the humerus, the elbow, the fore paws, the iliac crest, the greater trochanter of the femur, the stifle joint, the tarsal joint, the hind paws, the manubrium, and approximately at the level of C1, C7, T3, T12, L3, S1. Each marker was placed at least 4 cm apart to avoid interference with LED camera recording. The recording planes (X, Y, and Z) are also demonstrated.
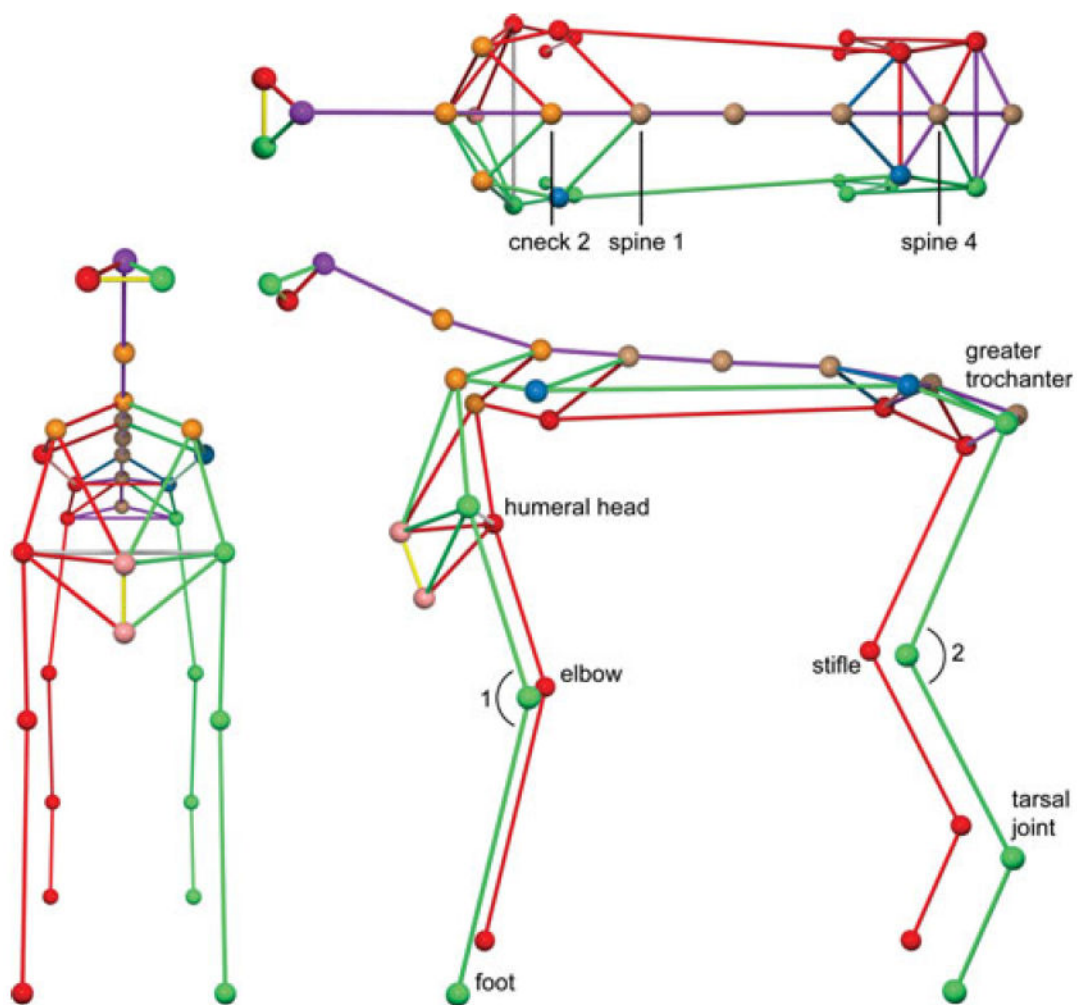
Fig 3.
3-D reconstruction showing "ball and stick figures". Top—Truncal sway was calculated utilizing 2 vectors. Vector v1 from cneck2 to spine1, Vector v2 from cneck2 to spine4. The maximum and minimal angles were the angles made between these two vectors in the *y*-plane. Bottom—Elbow flexion and extension was defined by the minimum and maximum angle created by the markers located at the level of the humeral head, elbow, and front foot (angle 1). Stifle flexion was determined based on the minimum and maximum angle created by the markers located at the greater trochanter, stifle joint, and tarsal joint (angle 2).
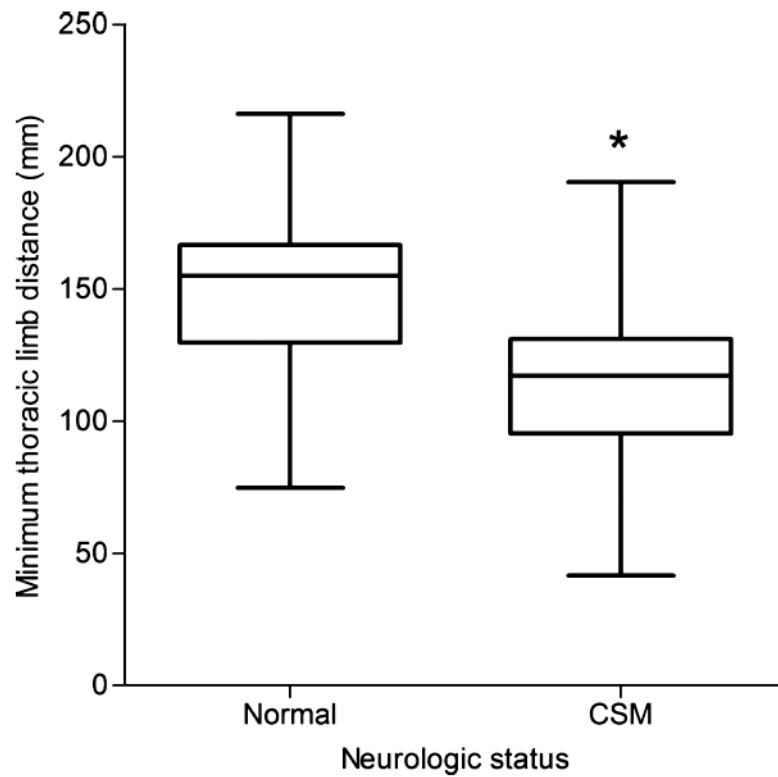
Figure 4.
Boxplot data of minimum thoracic limb distance in clinically normal and cervical spondylomyelopathy-affected Doberman Pinschers. $*P = .024$. The box represents the interquartile range (25–75%), the line in each box delineates the median value.
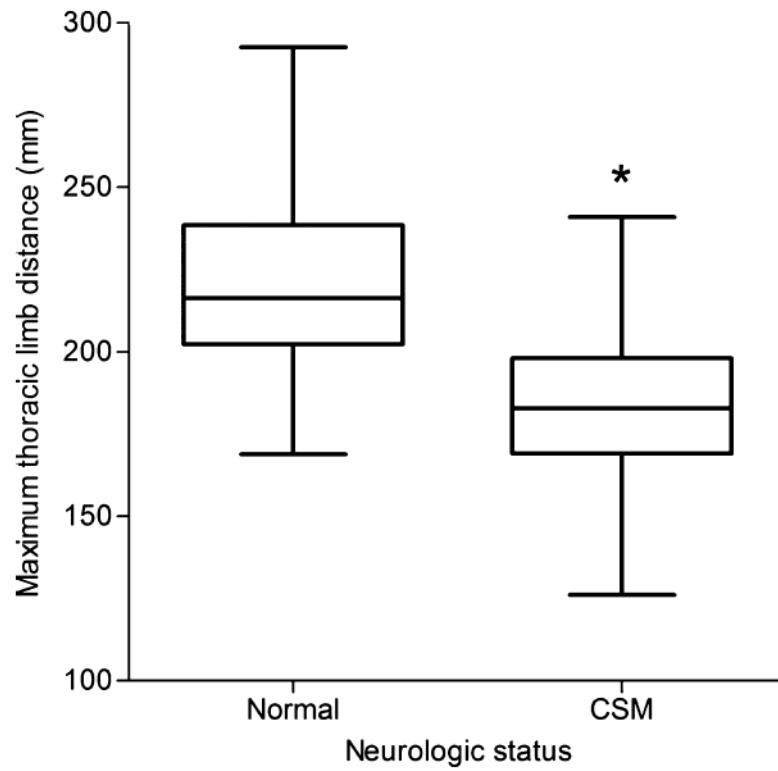
Figure 5.
Boxplot data of maximum thoracic limb distance in clinically normal and cervical spondylomyelopathy-affected Doberman Pinschers (n = 19). *P = .001. See Figure 4 for references.
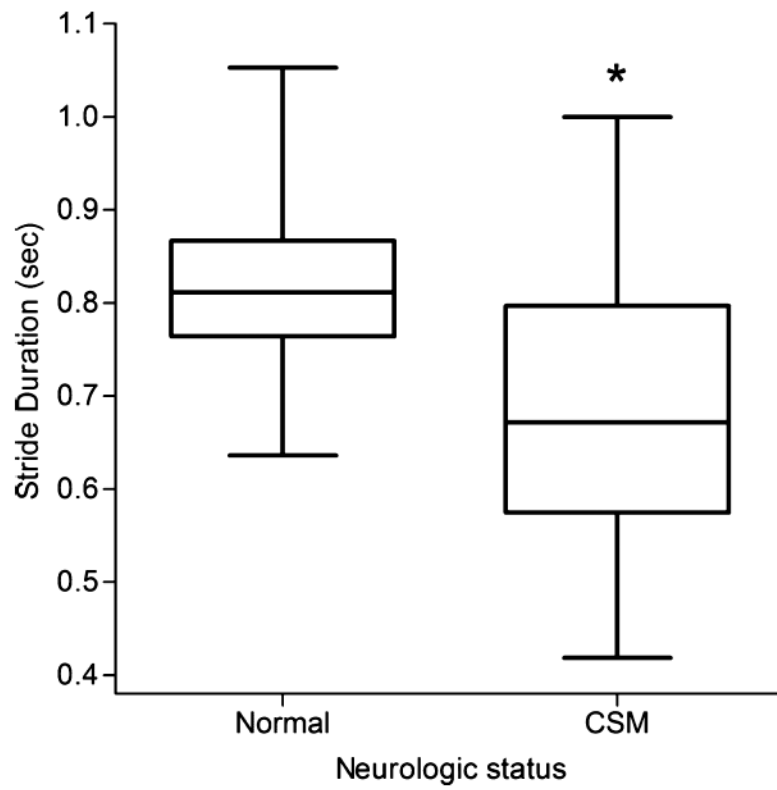
Figure 6.
Boxplot of thoracic limb stride duration in clinically normal and cervical spondylomyelopathy-affected Doberman Pinschers (n = 19). *P = .009

Table 1

Kinematic parameters (mean, 95% CI) of clinically normal and CSM-affected Doberman Pinschers

Parameter	Normal Dogs			Affected Dogs			P-Value[b]
	Mean and CV[a]	95% CI		Mean and CV	95% CI		
Number of strides (per 10 seconds)—thoracic limbs	4.3 (0.37)	3.4	5.2	3.5 (0.42)	2.6	4.4	.235
Number of strides (per 10 seconds)—pelvic limbs	4.1 (0.41)	3.2	5	2.7 (0.55)	1.7	3.6	.033[*]
Stifle flexion (°)	109 (0.06)	103	114	100 (0.14)	94	106	.048[*]
Stifle extension (°)	146	141	151	136	130	141	.009[*]
Elbow flexion (°)	106	102	109	102	98	106	.130
Elbow extension (°)	146	141	152	139	133	145	.077
Average flexion (°)	107 (0.05)	103	111	101 (0.08)	97	105	.023[*]
Average extension (°)	146 (0.03)	142	150	137 (0.06)	133	142	.005[*]
Pelvic limb stride height (mm)	83	73	93	84	73	95	.856
Thoracic limb stride height (mm)	75	63	87	90	78	103	.088
Average limb stride height (mm)	79.0	68.8	89.2	87.4	76.6	98.1	.268
Stride length—thoracic limbs (mm)	798	740	856	726	665	788	.099
Stride length—pelvic limbs (mm)	822	752	892	885	811	959	.224
Average stride length (mm)	811	756	865	808	751	865	.946
Stride duration—thoracic limbs (sec)	0.8 (0.08)	0.8	0.9	0.7 (0.19)	0.6	0.8	.009[*]
Stride duration—pelvic limbs (seconds)	0.8 (0.08)	0.8	0.9	0.8 (0.12)	0.8	0.9	.660
Average stride duration (seconds)	0.8	0.8	0.9	0.8	0.7	0.8	.143
Max thoracic limb distance (mm)	222 (0.11)	206	237	184 (0.13)	168	200	.001[*]
Min thoracic limb distance (mm)	146 (0.17)	128	165	116 (0.29)	97	135	.024[*]
Max pelvic limb distance (mm)	233	211	255	229	206	252	.824
Min pelvic limb distance (mm)	194	167	221	159	130	187	.079
Max spine angle (°)	10.5	9.3	11.7	11.2	9.9	12.4	.459
Min spine angle (°)	2.9	1.3	4.5	3.6	1.9	5.3	.567

CI, confidence interval; LF, left front; RF, right front; LH, left hind; RH, right hind; CSM, cervical spondylomyelopathy.

[*] P < .05.

[a]CV, coefficient of variation. CV was only established for selected parameters.

[b]P-value tests if the means are different between normal and affected dogs using a random-effects linear regression.