Thoracic Limb Angular Deformity in Chondrodystrophic Dogs: Repeatability of Goniometric Measurement of External Rotation and Carpal Valgus

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Abstract

Objective We aimed to provide repeatable methods for quantifying antebrachial valgus and rotation in dogs with and without complex angular deformities. Thus, we investigated the repeatability of two methods to measure carpal valgus and one method to measure external rotation of the thoracic limb in a standing position.

Study Design This was a prospective observer agreement study with a sample of 18 non-chondrodystrophic dogs as baseline and 43 chondrodystrophic dogs. The rotation measurements (ROT), modified valgus measurements (VALG-M), and established carpal valgus measurements (VALG) were done independently by two investigators. Repeatability was assessed with intraclass correlation coefficient (ICC).

Results The measured mean (± standard deviation) angles of ROT, VALG-M, and VALG for non-chondrodystrophic dogs were 14 degrees (± 5 degrees), 9 degrees (± 4 degrees), and 4 degrees (± 3 degrees) and 30 degrees (± 13 degrees) and 23 degrees (± 11 degrees) for ROT and VALG-M for chondrodystrophic dogs respectively. In non-chondrodystrophic dogs, ICC was low with mean errors of 1 to 6 degrees, whereas in chondrodystrophic dogs, intra- and intertester ICC was high for ROT and VALG-M with mean errors of 3 to 8 degrees.

Conclusion The ROT and VALG-M methods can be used as reliable tools to objectively quantify aspects of thoracic limb alignment for research, clinical, and screening purposes in both non-chondrodystrophic and chondrodystrophic dogs. The mean values of ROT, VALG-M, and VALG can be used as references for non-chondrodystrophic dogs in the standing position.

Keywords
- dog
- angular deformity
- chondrodystrophy
- valgus
- rotation
- radial torsion

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Introduction

Angular limb deformity caused by premature closure of the distal ulnar growth plate is a developmental disorder of the canine forelimb common in chondrodystrophic breeds.[1–4] Characteristically, this deformity presents as complex multiplanar conformational abnormalities in the structure of the thoracic limb such as carpal valgus, radial torsion, procurvatum and subluxation, elbow incongruity and external rotation of the limb arising at least from the elbow joint and radius.[1,3–7] In affected individuals, several abnormalities can be present simultaneously.[1–4,6,7] As a consequence, the deformity can result in secondary pathologies such as elbow dysplasia and osteoarthritis, causing welfare problems such as pain and lameness.[4,5,8] It can also affect limb biomechanics, causing changes in function such as gait and range of motion of the joints.[4,5] The deformity is more common and complex in chondrodystrophic breeds than in other breeds.[4,5,7,9]

Rotational deformities cause the carpal and elbow joints to be malaligned in different planes, rendering carpal valgus measurement from orthogonal radiographs problematic. Thus, the standard lateral and craniocaudal radiographic views do not allow accurate measurement of the valgus angle in chondrodystrophic limbs.[2,7,10–13] Computed tomography imaging has been used to measure specific aspects of angular deformity, such as radial torsion, but also overall axial alignment.[6,11–14] However, the need for sedation or anaesthesia and specialized facilities and the high costs make computed tomography a less attractive method for assessing a large quantity of the dog population such as in the case of screening for breeding health. Furthermore, due to the need for sedation or anaesthesia, computed tomography does not provide information on functional thoracic limb alignment during weight-bearing. To supplement these imaging modalities, there is a need for an additional practical method to assess the angulation of the forelimb in a functional setting.

A universal goniometer could be used for quantifying the angulation and alignment of a curved canine forelimb. It is a practical, inexpensive and non-invasive tool for measuring joint angles. It is widely used in physiotherapy and research in humans to determine joint position, passive joint range of motion and structural limb angulation and rotation.[15–20] Two studies have evaluated dogs' joint angles in a standing position,[21,22] although several publications exist for range of motion measurements in recumbency.[23–27] Anatomic landmarks for measuring the passive range of motion of different appendicular joints, including carpal valgus, have been established and validated in Labrador Retrievers and cats.[23,28] However, the previously established landmarks for dogs' carpal valgus measurement assume a straight antebrachium,[23] which poses a problem for measurements of the chondrodystrophic limb that can be curved in all three planes. These clinical observations and a pilot study highlighted a need for novel landmarks for measuring carpal valgus in the chondrodystrophic forelimb. Furthermore, a protocol for goniometric measurement of external rotation (ROT) of the limb is lacking.

The purpose of this study was to describe and investigate the reliability of practical and accessible novel goniometric methods for quantifying ROT and modified carpal valgus (VALG-M) of the thoracic limb in a standing position in chondrodystrophic and non-chondrodystrophic dogs. Additionally, the VALG-M is validated against a previously validated method for measuring carpal valgus (VALG). Lastly, we report reference ranges for ROT, VALG-M and VALG in a functional weight-bearing position for non-chondrodystrophic dogs.

Materials and Methods

The non-chondrodystrophic dogs were Labrador Retrievers, and the breeds selected to represent chondrodystrophic dogs were the Skye Terrier and Glen of Imaal Terrier. Use of goniometer has been validated in Labrador Retrievers and a reference for carpal valgus angle is available for this breed.[23] The Labrador Retrievers were recruited from the Guide Dog School of the Finnish Federation of the Visually Impaired, which screens their working dogs' hips and elbows based on the Finnish Kennel Club screening criteria. Inclusion criteria were an age of 1 to 7 years, an International Elbow Working Group elbow dysplasia status of 0/0 (normal), a Fédération Cynologique Internationale hip dysplasia status of A or B (normal or near normal) and no reported orthopaedic disease.[29,30] As the guide dog school for the visually impaired routinely investigates their dog population for elbow and hip dysplasia, this information was available for all dogs during the time of investigations. The dogs selected for the study were the dogs that were, at the time, physically present at the guide dog school for their occupational training. The chondrodystrophic dogs were recruited in the order of enrolment through their respective breed clubs as part of a larger series of studies on forelimb biomechanics of chondrodystrophic dogs. The inclusion criterion for chondrodystrophic dogs was an age of 1 to 10 years. The exclusion criterion was history of any orthopaedic surgical procedures. The owners of the dogs signed an informed consent form. The study was conducted during the years 2015 to 2017.

Axial rotation of the thoracic limb was measured with a 30-cm plastic universal goniometer with 1 degree increments. The ROT was measured by placing the goniometer axis under the metacarpal pad as shown in ►**Fig. 1**, the static arm parallel to the spine of the dog and the free arm along the third digit. As non-chondrodystrophic dogs may also occasionally be affected by angular anomalies of the thoracic limb, the repeatability of ROT was also investigated in the Labrador Retriever group. The ROT was measured identically in both groups of dogs.

Carpal valgus was measured using a 15-cm plastic universal goniometer with 1 degree increments. The VALG-M was measured with one arm placed toward the lateral epicondyle of the humerus, the axis placed on the centre of motion of the carpus and the other arm parallel to the line of the third digit. The VALG-M was measured identically in both groups of dogs. For chondrodystrophic dogs, both arms of the goniometer were

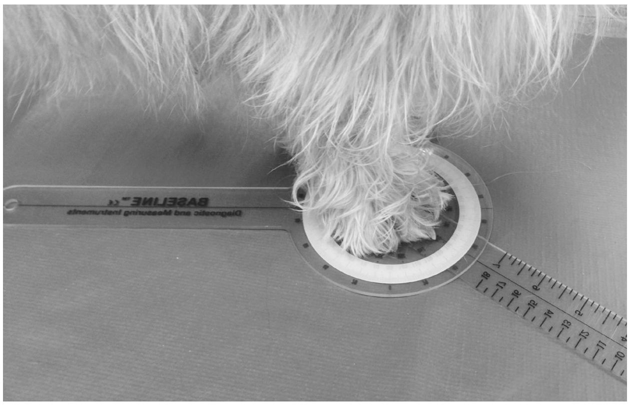

Fig. 1 A 30-cm plastic goniometer with its axis placed under the metacarpal pad for measuring external rotation of the thoracic limb in a standing position. The static arm of the goniometer was parallel to the spine of the dog and the free arm was along the third digit. The dog should be visually evaluated to have equal weight-bearing on both limbs when the measurement is performed.

shortened to the level of the dial, resulting in a total instrument diameter of 7.5 cm for a better fit to the limited space between the paw and the elbow (►**Fig. 2**).

To validate the novel VALG-M, we compared the repeatability and measured angles with the previously validated VALG method by performing both types of measurements on Labrador Retrievers. Thus, in the non-chondrodystrophic group, we additionally measured VALG using the method described by Jaegger and colleagues.[23]

During all measurements, an assistant was holding the dog in a neutral standing position on a non-slippery surface and the person making the measurements visually confirmed equal weight-bearing to ensure that the dog was not leaning in any one direction. The owner most commonly served as the assistant. To assess intra-tester repeatability, the measurements were done twice by a veterinary surgeon with minimal training in the use of the goniometer. To assess inter-tester repeatability, the measurements were then repeated once by an animal physiotherapist with 10 years of clinical experience. Adapted from Jaegger and colleagues,[23] the measurements were collected a minimum of 10 minutes apart and the observer was blinded from the other results by recording the value on a separate recording sheet, and revision of the other sets was not allowed. Both observers performed the measurements during the same day, to ensure invariant clinical status of the dogs between the measurements. Data from two to three dogs were collected on a single day.

Fig. 2 A 15-cm plastic goniometer with the arms cut to the level of the dial to fit the limited space in the chondrodystrophic limb for measuring carpal valgus. The resulting total diameter of the goniometer is 7.5 cm. One arm was placed toward the lateral epicondyle of the humerus, the axis placed on the center of motion of the carpus, and the other arm parallel to the line of the third digit.

Based on a power analysis for an expected power of 0.8, significance set at 0.05, and effect size at 0.5, a minimum sample size of 34 measurement pairs was required for the pairwise comparison of VALG and VALG-M means and 37 measurements per group for the pairwise comparison of chondrodystrophic and non-chondrodystrophic population means. Based on a priori power analyses and testing different variations, the effect size 0.5 was assessed to be able to be adequate to detect a 2-degree difference between groups, when calculated using the scarce available information on the means and standard deviations (SDs) for goniometric measurements in dogs. Jaegger and colleagues reported a carpal valgus mean angle of 12 degrees with an SD of 2 degrees. For the assessment, SD was doubled for chondrodystrophic dogs because we expected them to be a more heterogenous population than the Labradors studied by Jaegger and colleagues. The normality assumption was inspected using the Shapiro–Wilk test. In case the assumptions were violated, common data transformations were applied. The applied transformations are presented together with the results in ►**Tables 1** and **2**. The intra- and inter-

Table 1 Mean, standard deviation and confidence interval of the mean for external rotation, modified carpal valgus and established carpal valgus in chondrodystrophic dogs and in healthy non-chondrodystrophic dogs

Group	Measurement	Mean	SD	95% CI
Chondrodystrophic	Rotation	30 degrees	± 13 degrees	28–32 degrees
	VALG-M	23 degrees	± 11 degrees	22–25 degrees
Non-chondrodystrophic	Rotation	14 degrees	± 5 degrees	13–15 degrees
	VALG-M	9 degrees	± 4 degrees	9–10 degrees
	VALG	4 degrees	± 3 degrees	4–5 degrees

Abbreviations: CI, confidence interval; SD, standard deviation; VALG, established valgus method; VALG-M, modified valgus method.

Table 2 Intraclass correlation coefficients and confidence intervals for intra-tester repeatability of external rotation, modified valgus and established valgus

Measurement	Breed (*n*)	ICC	Lower 95% CI	Upper 95% CI
Rotation	Chondrodystrophic (86)[a]	0.942	0.913	0.962
	Non-chondrodystrophic (36)[b]	0.505	0.218	0.712
VALG-M	Chondrodystrophic (86)[c]	0.937	0.906	0.959
	Non-chondrodystrophic (36)[c]	0.819	0.675	0.903
VALG	Non-chondrodystrophic (36)[a]	0.414	0.107	0.650

Abbreviations: CI, confidence interval; ICC, intraclass correlation coefficient; n, number of measured limbs; VALG, established valgus method; VALG-M, modified valgus method.
In case the normality assumption was violated, common data transformations were used: [a]Untransformed, [b]Logarithmic, [c]Square root.

tester repeatability of goniometric measurements were evaluated by intraclass correlation coefficients (ICCs) using a two-way random model with absolute agreement. The ICC is the proportion of between-subject variation relative to the inter-measurement variation and is commonly used to describe repeatability of goniometric measurements in human physiotherapy research.[18–21] For the purpose of description, an ICC of 0.81 to 1.00 was considered high, 0.61 to 0.80 moderate, and less than 0.60 low.[31] As the clinically significant error magnitude for these measurements is unknown, we chose a boundary of less than 5 degrees to represent good agreement between measurements. This boundary was based on the previously reported measurement error of 1 to 6 degrees for goniometric range of motion measurements for dogs.[23] The analysis was conducted by group and point of measurement. Results from both investigators were combined to calculate the population means for chondrodystrophic and non-chondrodystrophic dogs for each point of measurement. The differences in population means between breeds were investigated using independent *t*-test. A paired *t*-test was used to analyse the differences between means of VALG-M and VALG. Statistical analyses were done using SAS System for Windows (v. 9.3), R for Windows (v. 3.4.2), and IBM SPSS Statistics (v. 24).

Results

Dogs

The non-chondrodystrophic group consisted of 36 thoracic limbs (18 dogs) for both intra- and inter-tester measurements. In the chondrodystrophic group, the intra-tester measurements were performed on a total of 86 thoracic limbs (43 dogs), and the inter-tester measurements on a total of 46 thoracic limbs (23 dogs). When measurements from both investigators were combined, 108 measurements for each point of measurement were available for non-chondrodystrophic dogs and 218 measurements for chondrodystrophic dogs to calculate the population means in ►**Table 1**. The reason for the discrepancy in the numbers between the groups is because the second observer was not always available during the chondrodystrophic dogs' appointment, which is why there is a larger number of dogs included in the intratester measurements than the intertester measurements. To further explain, the first observer performed measurements twice and the second observer performed the measurements once, adding up to three measurements per point of measurement for each limb (34 limbs × 3 = 108 for the non-chondrodystrophic dogs). For the chondrodystrophic dogs, 86 limbs were measured twice by observer one, and the second observer measured 46 of those for a third time (86 limbs × 2 + 46 = 218 for the chondrodystrophic dogs). The study population is summarized in ►**Table 3**.

Mean Values of ROT, VALG-M and VALG

The mean (± SD) angle for ROT was 14 degrees (± 5 degrees) for non-chondrodystrophic dogs and 30 degrees (± 13 degrees) for chondrodystrophic dogs. The mean VALG-M angle was 9 degrees (± 4 degrees) for non-chondrodystrophic dogs and 23 degrees (± 11 degrees) for chondrodystrophic dogs. The mean VALG angle for non-chondrodystrophic dogs was 4 degrees (± 3 degrees). The

Table 3 Signalment of the 43 chondrodystrophic and 18 non-chondrodystrophic dogs with mean age and weight

Group	Breed	*n*	Sex		Mean age, years (range)	Mean (SD) weight (kg)
			F	M		
Chondrodystrophic	Total	43	23	20	3.5 (1.0–11.0[a])	17.0 (±3.7)
	Skye Terrier	15	8	7	2.5 (1.0–5.0)	14.4 (±2.5)
	Glen of Imaal Terrier	28	15	13	4.1 (1.0–11.0)	18.3 (±3.6)
Non-chondrodystrophic	Labrador Retriever	18	12	6	1.8 (1.0–6.7)	27.2 (±3.6)

Abbreviations: F, female; M, male; *n*, number of dogs; SD, standard deviation.
[a]After recruitment, one Glen of Imaal terrier had reached 11 years of age (1 year above inclusion age) by the time of the appointment.

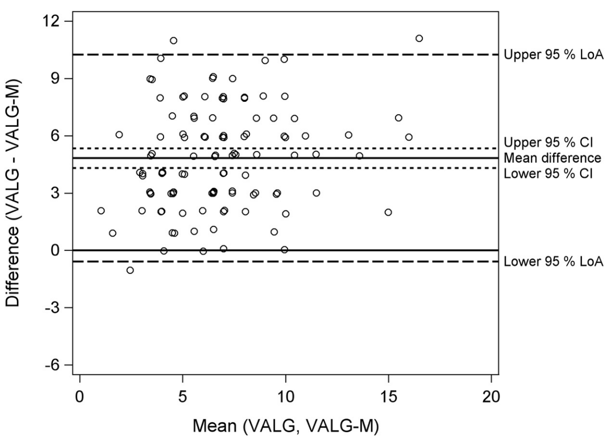

Fig. 3 A Bland-Altman plot demonstrating the 5 degrees mean difference between modified valgus measurements (VALG-M) and established carpal valgus measurements (VALG) in Labrador retrievers. The 95% confidence interval of the mean (CI) and the 95% limits of agreement (LoA) are shown in the image.

confidence intervals of the mean in all measurements were narrow, ranging from 1 to 4 degrees. The difference in group means between non-chondrodystrophic and chondrodystrophic dogs was significant for both ROT ($p < 0.001$) and VALG-M ($p < 0.001$). In addition, a significant 5-degree difference in the measurement results between VALG-M and VALG methods was noted ($p < 0.001$) (►**Fig. 3**).

Repeatability of ROT

Intra-tester repeatability of ROT was low in the non-chondrodystrophic group (ICC: 0.505) but high in the chondrodystrophic group (ICC: 0.942) (►**Table 2**). Inter-tester repeatability was low (ICC: 0.390) in the non-chondrodystrophic group and moderate (ICC: 0.646) in the chondrodystrophic group (►**Table 4**). However, the absolute mean errors (± SD) for ROT measurements were considered small for all points of measurements, varying from 4 degrees (± 3 degrees) to 8 degrees (± 7 degrees), as reported in ►**Table 4**. Additionally, 53 and 44% of the inter-tester measurement pairs in the non-chondrodystrophic and chondrodystrophic groups, respectively, had less than 5 degrees measurement error (►**Table 5**).

Repeatability of VALG-M

The intra-tester repeatability of the novel VALG-M method was high in both non-chondrodystrophic (ICC: 0.819) and chondrodystrophic groups (ICC: 0.937) with small mean errors of 1 (± 1 degrees) and 3 degrees (± 3 degrees) respectively (►**Tables 2** and **5**). The inter-tester repeatability was low in the non-chondrodystrophic group (ICC: 0.292) and moderate in the chondrodystrophic group (ICC: 0.740), but the inter-tester absolute mean errors (± SD) were small for both groups: 3 (± 3 degrees) and 5 degrees (± 4 degrees) respectively (►**Tables 4** and **5**). The measurement error was less than 5 degrees in 75% of the repeated measurements in non-chondrodystrophic dogs and in 65% in chondrodystrophic dogs (►**Table 5**).

Table 4 Intraclass correlation coefficients and confidence intervals for inter-tester repeatability of external rotation, modified valgus and established valgus measurement by two methods

Measurement	Breed (n)	ICC	Lower 95% CI	Upper 95% CI
Rotation	Chondrodystrophic (86)^{a}	0.646	0.338	0.810
	Non-chondrodystrophic (36)^{b}	0.390	−0.087	0.700
VALG-M	Chondrodystrophic (86)^{c}	0.740	0.570	0.848
	Non-chondrodystrophic (36)^{c}	0.292	−0.013	0.555
VALG	Non-chondrodystrophic (36)^{a}	0.248	−0.061	0.525

Abbreviations: CI, confidence interval; ICC, intraclass correlation coefficient; n, number of measured limbs; VALG, established valgus method; VALG-M, modified valgus method.
In case the normality assumption was violated, common data transformations were used: ^{a}Untransformed, ^{b}Logarithmic, ^{c}Square root.

Table 5 Absolute mean difference (degrees) and standard deviation of measurement pairs for intra-tester and inter-tester measurements and the number (*n*) and proportion of agreement (%) with an accepted error of < 5 degrees difference between measurements for inter-tester measurements

Breed	Variable	Intra-tester	Inter-tester	< 5 degrees
		Mean (SD)	Mean (SD)	*n* (%)
Chondrodystrophic	Rotation	4 degrees (3 degrees)	8 degrees (7 degrees)	20 (44)
	VALG-M	3 degrees (3 degrees)	5 degrees (4 degrees)	30 (65)
Non-chondrodystrophic	Rotation	4 degrees (3 degrees)	6 degrees (4 degrees)	19 (53)
	VALG-M	1 degree (1 degree)	3 degrees (3 degrees)	27 (75)
	VALG	2 degrees (2 degrees)	3 degrees (2 degrees)	28 (78)

Abbreviations: SD, standard deviation; VAGL-M, modified valgus method; VALG, established valgus method.

Repeatability of VALG

The VALG measurements were only performed for the non-chondrodystrophic group. The intra-tester repeatability of VALG was considerably lower (ICC: 0.414) than for VALG-M, but the inter-tester repeatability was similarly low for both methods of measuring carpal valgus (►**Tables 2** and **4**). Similar to the mean errors for VALG-M, the absolute mean errors (± SD) of intra- and inter-tester VALG measurements were small: 2 degrees (± 2 degrees) and 3 degrees (± 2 degrees) respectively (►**Table 4**). The measurement error was less than 5 degrees in 78% of the inter-tester measurement pairs, which was slightly higher than for VALG-M (►**Table 4**).

Discussion

The repeatability of ROT, VALG, and VALG-M was low for all measurements in the non-chondrodystrophic group, with the exception of intra-tester VALG-M, which was moderate in these dogs. On the contrary, repeatability of the measurements was high or moderate for all intra-tester measurements and moderate for inter-tester measurements in the chondrodystrophic group. In the non-chondrodystrophic group the ICC may appear low either due to large measurement errors or, alternatively, due to very little variation within the group.[32] Therefore, the mean errors and SDs of the measurements were also assessed. The SDs in the non-chondrodystrophic dogs were 3 to 5 degrees, while in the chondrodystrophic group the SDs were much larger (11–13 degrees), indicating that the non-chondrodystrophic dogs had less variation within the group. Thus, low ICC values in the non-chondrodystrophic group are likely to reflect homogeneity of the group rather than true low repeatability between measurements, as further evidenced by the small mean errors.

As previously published in humans,[19] the intra-tester repeatability was notably higher than the inter-tester repeatability for all points of measurement in both groups of dogs. Thus, for optimal measurement consistency across time, the measurements should be made by the same person at all time points. The level of inter-tester repeatability is, nevertheless, likely to be sufficient for selected clinical applications, further research in forelimb biomechanics and orthopaedic screening for breeding purposes. However, presurgical planning for correction of angular deformities should rely on images obtained by radiography or computed tomography for maximal accuracy.

The intra-tester repeatability was higher for VALG-M than for VALG measurements within the same population of non-chondrodystrophic dogs. This could be explained by a more objective estimate of the point-like landmark of the humeral epicondyle (VALG-M) than the wider definition of radial axis (VALG). Despite both methods having a similarly low inter-tester ICC, the mean errors for both methods were small and unlikely to have clinical significance. When comparing the measured angles of VALG-M and VALG within the non-chondrodystrophic group, a significant difference of 5 degrees was noted in the mean values between the two methods (►**Fig. 3**). However, this was expected because the lateral epicondyle is situated more laterally than the radial axis, creating a difference in the measured angle between these methods. Thus, the measurer needs to be aware of this and apply the appropriate reference range for the landmark chosen.

Low intra-tester mean errors of 1 to 6 degrees have been reported in goniometric range of motion measurements done in dogs.[23] In our study, the mean error in intra-tester measurements was found to be even lower for all points of measurement (1–4 degrees). Mean errors for inter-tester measurements have not been reported in dogs, but in human studies they have ranged from 0 to 28 degrees.[15,33–35] In comparison, the mean errors in our study for the inter-tester measurements were low for both valgus (3–5 degrees) and rotation (6–8 degrees).

As a by-product of the repeatability assessment, our study produced mean values for the carpal valgus angles as well as external rotation for these two dog populations. A recent study used computed tomography to measure the external rotation of the thoracic limb and reported a rotation of 35.4 degrees in normal limbs, which is considerably larger than in our study (14 degrees).[6] However, they defined the humeral anatomic axis as the plane of comparison for the more distal limb, while we measured the whole limb's rotation against the dog's sagittal axis, complicating the comparison of the results.[6] For non-chondrodystrophic dogs, we report smaller (4 ± 3 degrees) mean VALG angles than Jaegger and colleagues (12 ± 2 degrees) despite using the same anatomic landmarks and the same breed of dogs.[23] Additionally, the maximal carpal valgus for small and medium sized chondrodystrophic dogs was recently reported to be 53 and 48 degrees in the recumbent position respectively.[27] These values are much larger than what we report for carpal valgus in chondrodystrophic dogs (23 ± 11 degrees). The differences may be due to the standing position in our study, whereas Jaegger and colleagues and Reusing and colleagues both report the maximal valgus angle on a laterally recumbent dog.[23,27] It would seem logical that the standing position would employ the end range of the lateral joint position, but this does not seem to be the case. One reason for this might be that the forces created by muscles and tendons support the joint during weight-bearing.

Although we report mean values for chondrodystrophic dogs, it should be noted that the chondrodystrophic dogs were not selected based on their orthopaedic health, and the mean ROT and VALG-M angles for this group were significantly different than those of the non-chondrodystrophic group. Unfortunately, studies on the demarcation of normality from different degrees of deformity as well as its effects on function are lacking. In addition, the non-chondrodystrophic group consisted solely of adult Labrador Retrievers. Due to possible breed-specific differences, these mean values should be used cautiously as a reference for other non-chondrodystrophic breeds, and even more so if measurements are taken from skeletally immature dogs.

Concerning limitations of the study, there is a risk for intra-observer recall bias, as the measurements were taken only 10 minutes apart. However, the bias was minimized by the observer performing other types of tasks in between data acquisition. The minimum of 10 minutes, which was decided to be sufficient time between repeated measurements, is similar to the 15 minutes used by Jaegger and colleagues when validating goniometry. Furthermore, the elapsed time period was often more than 10 minutes, as the measurements were repeated at convenient time points during a 3-hour visit, when also other tests, related to another study, were performed.

Both of the new measurement methods, ROT and VALG-M, have some characteristics that should be considered when acquiring measurements. The animal's positioning of the paw may vary slightly between measurements since the standing position represents a functional position and is intrinsically slightly different each time. Consequently, a strictly fixed value is not to be expected. Nevertheless, care should be taken to ensure that the dog is standing in a neutral position with equal weight-bearing between the forelimbs to ensure consistency of measurements. Such measurements that have an inherent variability, for example, those taken in a functional setting, might be more accurately represented by a range or a distribution of several measurements in an individual dog, although this could prove laborious and impractical in a clinical setting.

In addition, the difference between the anatomy of non-chondrodystrophic and chondrodystrophic breeds may have an effect on the measurements. First, the anatomic landmarks of VALG-M, the lateral humeral epicondyle and carpus, are situated much further away from each other in non-chondrodystrophic dogs. Thus, the visual evaluation of the placement of the arms of the goniometer is more prone to variation in non-chondrodystrophic dogs than in chondrodystrophic dogs, but this can be easily overcome by choosing a goniometer with longer arms. Second, placing the instrument parallel to the spine when measuring external rotation of the thoracic limb becomes more challenging as the distance between the goniometer and the spine increases in non-chondrodystrophic dogs. For large breeds, it could be worth investigating whether the repeatability for ROT is higher with some additional method to evaluate the parallel placement of the goniometer with the spine. Interestingly, despite these challenges for measuring these angles in normal-sized dogs, the mean errors between measurements were smaller in this group than in the chondrodystrophic group.

To conclude, the results indicate high repeatability for both ROT and VALG-M in chondrodystrophic dogs. Despite the low repeatability in the non-chondrodystrophic group, the measurement errors were small enough to make the methods clinically applicable. These methods can be used to objectively quantify thoracic limb alignment in terms of external rotation and carpal valgus in a practical way to provide information about limb conformation for clinical use, further research in forelimb biomechanics and orthopaedic screening for breeding purposes. However, it should be kept in mind that these measurements only partially describe the complex forelimb geometry, and additional measurement methods are still needed for a more thorough understanding of the deformity. In addition, the mean values for non-chondrodystrophic dogs can be used as a reference for carpal valgus and external rotation in the standing position.

Conflicts of Interest

The authors have no conflicts of interest to disclose.

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