Original Research

Establishment of Normal Mechanical Tibial Joint Angles in Dachshunds

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Vet Comp Orthop Traumatol

Abstract

Objective The aim of this study was to establish breed-standard mechanical tibial joint reference angles in the frontal plane in Dachshunds.

Study Design Craniocaudal ($n = 38$) and mediolateral ($n = 32$) radiographs of normal tibiae from Dachshunds were retrospectively reviewed. The mechanical medial proximal, mechanical medial distal, mechanical caudal proximal and mechanical cranial distal tibial angles were measured on three occasions by two separate observers using previously established methodology. Interclass correlation coefficient was used to assess the reliability of radiographic measurements.

Results The mean and standard deviation for mechanical medial proximal, mechanical medial distal, mechanical caudal proximal and mechanical cranial distal were 93.1 degrees ± 4.2, 97.5 degrees ± 3.9, 75.3 degrees ± 3.7 and 85.0 degrees ± 5.3 respectively. Intra-observer reliability was good to excellent for all measures, while inter-observer reliability was moderate to excellent in the frontal plane and poor to good in the sagittal plane. Dachshund-specific joint reference angles were similar to a range of previously reported non-chondrodystrophic breeds in the frontal plane but differed to most in the sagittal plane.

Conclusion Dachshund tibial joint reference angles are reported which can be used in surgical planning for correction of bilateral pes varus.

Keywords
- Dachshund
- pes varus
- joint reference angles
- mechanical tibial joint angles
- angular limb deformity

Introduction

Pes varus is a recognized angular limb deformity to which Dachshunds are predisposed and although the aetiology is poorly understood, it is suspected to be an hereditary condition.[1] Typically, owners identify a developing 'bow-legged' pelvic limb appearance due to varus deviation of the tarsus secondary to eccentric medial closure of the distal tibial physis. Subsequent alterations in the alignment of the limb can result in abnormal mechanical loading across the talocrural joint causing excessive lateral strain on soft-tissue structures,

received
June 6, 2020
accepted after revision
November 24, 2020

Georg Thieme Verlag KG,
Rüdigerstraße 14,
70469 Stuttgart, Germany

DOI https://doi.org/10.1055/s-0040-1722336.
ISSN 0932-0814.

accelerated development of osteoarthritis and lameness.[2] To reduce these sequalae, a corrective osteotomy is typically recommended.[3–5] Orthogonal radiographs are most commonly used to assess and quantify the deformity in the frontal and sagittal plane. To aid surgical planning, normal values are determined from the unaffected contralateral limb where unilateral pes varus is present, or alternatively, corrective measurements are based on published breed normal values.[6]

Normal mechanical tibial joint reference angles have been established in Labradors and medium cross breeds, small breeds and non-chondrodystrophic dogs.[7–9] However, as these breeds have different long bone conformation from chondrodysplastic Dachshunds, the available joint reference angles may not be applicable. Given the hereditary nature of the condition, it is not uncommon for pes varus to be present bilaterally in Dachshunds.[4,10] In such cases requiring bilateral corrective osteotomies without a contralateral normal limb, breed-specific joint reference angles are required to optimize surgical outcomes.

The objective of this study was to establish Dachshund breed-standard tibial joint reference angles in the frontal and sagittal planes to allow accurate correction of bilateral pes varus. The hypothesis was that tibial joint reference angles would be different in the chondrodystrophic Dachshund compared with previously established normal tibial joint reference angles.

Materials and Methods

The study was approved by the institutional Ethical Review Board at the lead institution (URN SR2019–0297) prior to commencement. A sample size calculation was performed using preliminary data of frontal plane joint reference angles from the primary author's institution. Preliminary data contained 15 samples for each joint type. *A priori* confidence interval (CI) simulations were performed to determine the required number of samples needed for the study. The simulation determined what sample size was needed to reduce the CI of the preliminary data by 50%. The 50% threshold was a compromise between reducing the CI while not requiring an unattainable number of samples. Based on this, 33 samples were required to achieve an estimate of the population mean.

Data Collection

Electronic medical records from the lead institution (The Queen Mother Hospital for Animals, Royal Veterinary College) and two collaborating referral centres (Langford Vets, University of Bristol; North Downs Specialist Referrals) between 2009 and 2019 were reviewed to identify suitable Dachshunds. Cases excluded skeletally immature patients, a history of lameness associated with conditions affecting the tibia of the radiographed limb, as well as clinical or radiographic tibial, stifle or tarsal abnormalities. The reason for the radiographic study was recorded and categorized into four groups: spinal disease, control radiograph of a normal contralateral limb (e.g. contralateral tibial fracture), tibial radiograph of a limb with a non-tibial fracture (e.g. an ipsilateral distal femoral fracture) and other (comprising numerous non-tibial disease presentations). Additional variables extracted from the medical records were age, weight and gender of the Dachshunds.

Radiographic Measurements

Radiographic inclusion criteria required a straight positioned diagnostic quality projection that included the entire tibia and tarsus. For the caudocranial view, appropriate positioning was defined as including the patella positioned in the centre of the trochlear sulcus, fabellae bisected by the femoral cortices and the medial border of the calcaneus was aligned with the base of the sulcus of the talus.[11] For the mediolateral view, appropriate positioning was defined by superimposition of the femoral and tibial condyles.[12] Joint angles were measured using an open source DICOM image viewer (Horos, ©Horosproject.org, Version 3.0, 2019, Annapolis, Maryland, United States). The mechanical medial proximal tibial angle (mMPTA), mechanical medial distal tibial angle (mMDTA), mechanical caudal proximal tibial angle (mCaPTA) and mechanical cranial distal tibial angles (mCrDTA) were defined according to previously established methods.[7,8]

Measurements were obtained on three different occasions by two independent observers: a veterinarian (CB) and a board-certified surgeon (AP).

Statistical Analysis

All statistical analyses were performed using commercially available software (IBM SPSS Statistics for Windows, Version 26.0, Released 2019, Armonk, New York, United States). Descriptive statistics were generated for relevant variables including weight, age and gender. Data were assessed for normality using the Shapiro–Wilk test and analysed for the presence outliers using the outlier labelling rule ($K = 2.2$).[13] Interclass correlation coefficient (ICC) and their 95% CI based on absolute-agreement, 2-way mixed effects model for multiple measurements, that is, ($K = 3$) and multiple observers, that is, ($K = 2$) were determined to assess intra-observer and inter-observer agreement respectively.[14]

Combined means and standard deviations were calculated for each joint reference angle. Paired *t*-tests were utilized to identify any difference in joint reference angle between male and female dogs, and between left and right limb. A linear regression was performed to assess for any impact of age and weight on joint reference angle. One-way analysis of variance (ANOVA) was then performed to assess for variance between joint reference angle and category of reason for radiography. Significance was set at $p < 0.05$. One-sample *t*-tests were used to compare mean Dachshund joint reference angel to previously published tibial joint reference angle from different breeds.[8–10,15–20]

Results

A total of 38 caudocranial and 32 mediolateral radiographic views from 25 dogs, comprising 23 left and 15 right tibiae, met the inclusion criteria. Thirteen of the dogs were female and twelve were male. Age ranged from 5 months to 16.4 years with a mean age of 3.8 years, and weight ranged from

3.5 to 16.2 kg with a mean weight of 7.7 kg. Radiographs were obtained for spinal disease in seven dogs, contralateral control radiographs in 10 dogs, radiographs included as part of workup for a non-tibial fracture in the ipsilateral limb in 8 dogs and for other reasons in 13 dogs. All data were normally distributed.

The mean and standard deviations for mMPTA, mMDTA, mCaPTA and mCrDTA were 93.1 degrees ± 4.2, 97.5 degrees ± 3.9, 75.3 degrees ± 3.7 and 85.0 degrees ± 5.3 respectively (►**Table 1**). There was no statistical difference in joint reference angle between male and female or between left and right limb. Linear regression demonstrated no significant impact of age and weight on mMPTA ($p = 0.73$, $R^2 = 0.02$), mMDTA ($p = 0.36$, $R^2 = 0.07$), mCaPTA ($p = 0.59$, $R^2 = 0.05$) or mCrDTA ($p = 0.16$, $R^2 = 0.15$).

One-way ANOVA demonstrated no significant difference in joint reference angles between aetiology groups for mMPTA ($p = 0.05$), mMDTA ($p = 0.44$) and mCrDTA ($p = 0.53$). However, a significant difference in joint reference angle was identified between groups for mCaPTA ($p = 0.02$). Tukey's HSD post hoc test identified a significant difference between mCaPTA in Dachshunds where radiographs were taken for non-tibial fractures in the recorded limb and Dachshunds presenting for other (comprising numerous non-tibial disease presentations) ($p = 0.02$), with the mCaPTA mean 5.3 degrees less in the other group. There was no significant difference between mCaPTA when comparing spinal disease and control radiograph of a normal contralateral group.

Intra-observer agreement estimates based on 95% CI were excellent for all angles for one observer and good to excellent for the other (►**Table 2**). Inter-observer agreement was good to excellent for mMPTA, moderate to excellent for mMDTA, moderate to good for mCaPTA and poor to good for mCrDTA.[14]

Discussion

This study established normal tibial joint reference angles for a small chondrodystrophic breed—the Dachshund, in the frontal and sagittal plane. The Dachshund joint reference angles reported in this study can be utilized in the correction of bilateral angular limb deformities in the frontal plane, such as pes varus. However, when unilateral deformity is present, the current recommendation of using the contralateral limb as a control should remain.

Interestingly, previous publications have corrected mMDTA of clinical pes varus cases to 96 degrees, which

Table 1 Mean and standard deviation tibial joint reference angles are reported for normal Dachshunds. Comparison to previously published joint reference angles in multiple other breeds is also presented[9–11,17–21,31]

Plane	Joint angle	Dachshund mean ± SD	Previously published joint reference angle Compared with Dachshund (One-sample *t*-test [*p*-value])	Previously published breed and source
Frontal	mMPTA	93.1 ± 4.2	93.3 ($p = 0.704$)	Medium and large breed dogs[8]
			93.4 ($p = 0.792$)	Labradors with CCLD[8]
			95.1 ($p = 0.006$)*	Non-chondrodystrophic small breeds with MPL[10]
			97.3 ($p = 0.000$)*	Non-chondrodystrophic small breeds without MPL[10]
			96.9 ($p = 0.000$)* 97.1 ($p = 0.000$)* 98.4 ($p = 0.000$)* 103.1 ($p = 0.000$)*	Chihuahuas with grade I, II, III and IV MPL respectively[16]
			99.1 ($p = 0.000$)* 93.1 ($p = 0.979$) 92.6 ($p = 0.454$) 93.3 ($p = 0.792$)	Chihuahuas without MPL[16] Various breeds with unilateral, subsequent bilateral and bilateral respectively[19]
	mMDTA	97.5 ± 3.9	95.9 ($p = 0.017$)*	Medium and large breed dogs[8]
			96.3 ($p = 0.059$)	Labradors with CCLD[8]
			96.8 ($p = 0.227$)	Non-chondrodystrophic small breeds with MPL[10]
			98.1 ($p = 0.425$)	Non-chondrodystrophic small breeds without MPL[10]
			93.4 ($p = 0.000$)*	Chihuahuas without MPL[16]
			94.8 ($p = 0.000$)* 93.3($p = 0.000$)* 95.0 ($p = 0.000$)* 97.3 ($p = 0.659$)	Chihuahuas with grade I, II, III and IV MPL respectively[16]
			94.9 ($p = 0.000$)* 95.6 ($p = 0.004$)* 95.8 ($p = 0.008$)*	Various breeds with unilateral, subsequent bilateral and bilateral CCLD respectively[19]

(*Continued*)

Table 1 (*Continued*)

Plane	Joint angle	Dachshund mean ± SD	Previously published joint reference angle Compared with Dachshund (One-sample *t*-test [*p*-value])	Previously published breed and source
Sagittal	mCaPTA	75.3 ± 3.7	64.8 ($p = 0.000$)*	Medium and large breed dogs and Labradors with CCLD[9]
			74.8 ($p = 0.432$)	Non-chondrodystrophic small breeds without MPL[10]
			65.4 ($p = 0.000$)*	Non-chondrodystrophic small breeds with MPL[10]
			63.1 ($p = 0.000$)*	Chihuahuas without MPL[16]
			63.5 ($p = 0.000$)* 67.1 ($p = 0.000$) 63.9 ($p = 0.000$) 65.1 ($p = 0.000$)	Chihuahuas with grade I, II, III and IV MPL respectively[16]
			74.9 ($p = 0.523$)*	Basset hounds[16]
			52 ($p = 0.000$)	West Highland White Terriers[16]
			67.5 ($p = 0.000$)	Greyhounds with and without CCLD[a]
			62.0 ($p = 0.000$)	Labradors without CCLD[a]
			64.1 ($p = 0.000$) 63.8 ($p = 0.000$) 64.1 ($p = 0.000$) 61.8 ($p = 0.000$)	Labradors, Rottweilers, Boxers German Shepherd dogs respectively with CCLD[17,20]
			62.0 ($p = 0.000$) 63.0 ($p = 0.000$) 63.6 ($p = 0.000$)	Various breeds with unilateral, subsequent bilateral and bilateral respectively[19]
			66.3 ($p = 0.000$) 71.9 ($p = 0.000$)	Various breeds with and without CCLD respectively[18]
	mCrDTA	85.0 ± 5.3	86.3 ($p = 0.179$)*	Non-chondrodystrophic small breeds without MPL[10]
			86.1 ($p = 0.254$)*	Non-chondrodystrophic small breeds with MPL[10]
			81.6 ($p = 0.001$)	Medium and Large breed dogs and Labradors with CCLD[9]
			91.9 ($p = 0.000$)	Chihuahuas without MPL[16]
			92.2 ($p = 0.000$) 88.0 ($p = 0.003$) 91.8 ($p = 0.000$) 88.3 ($p = 0.001$)	Chihuahuas with grade I, II, III and IV MPL respectively[16]
			94.9 ($p = 0.000$) 95.6 ($p = 0.000$) 95.8 ($p = 0.000$)	Various breeds with unilateral, subsequent bilateral and bilateral CCLD[19]

Abbreviations: CCLD, cranial cruciate ligament disease; mCaPTA, mechanical caudal proximal tibial angle; mCrDTA, mechanical cranial distal tibial angles; mMDTA, mechanical medial distal tibial angle; mMPTA, mechanical medial proximal tibial angle; MPL, medial patella luxation; SD, standard deviation.

Note mCaPTA was calculated where was tibial plateau angle (TPA) reported based on assumption that mCaPTA = 90 degrees − TPA.

*Significant difference between Dachshund joint reference angle and previously reported value.

[a]Many different breed dogs were reported in this publication.[20] The two breeds with the highest numerical mCaPTA value were chosen for comparison. As statistical significance was achieved with these values, additional breeds are not documented here.

was within the range of our new breed-standard Dachshund mMDTA of 98 ± 4 degrees.[4] As the Dachshund is both small and chondrodystrophic, it was hypothesized that long bone conformation and therefore joint reference angles would be different to that of other breeds. Despite different long bone morphology, tibial joint references remain similar between Dachshunds and other breeds in the frontal plane (►**Table 1**). The mean mMPTA in Dachshunds is similar to non-chondrodystrophic medium to large breeds, with larger values reported for smaller breeds and those with medial patella luxation, which may be a feature of the increased curvature in the frontal plane associated with medial patellar luxation.[21] Conversely, mMDTA values in this Dachshund population were similar to smaller breed dogs with smaller values reported in medium to large breed dogs. The finding of a greater mMDTA value in Dachshunds compared with medium to large breed dogs suggests that medial deviation of the pes is not a conformational feature in normal Dachshunds.

Table 2 Interclass correlation coefficients (ICC) and their 95% confidence intervals (CI) for all joint reference angles based on absolute-agreement, 2-way mixed effects model for multiple measurements ($K = 3$) and multiple raters ($K = 2$)

	Intra-observer reliability						Inter-observer reliability		
	Observer 1 ($K = 3$)			Observer 2 ($K = 3$)			Between observers ($K = 2$)		
	ICC	95% CI		ICC	95% CI		ICC	95% CI	
mMPTA	0.985	0.975	0.992	0.974	0.955	0.986	0.935	0.874	0.966
mMDTA	0.966	0.941	0.981	0.956	0.926	0.976	0.887	0.505	0.958
mCaPTA	0.961	0.930	0.980	0.855	0.739	0.925	0.769	0.531	0.887
mCrDTA	0.969	0.943	0.984	0.887	0.798	0.941	0.763	0.426	0.893

Abbreviations: mCaPTA, mechanical caudal proximal tibial angle; mCrDTA, mechanical cranial distal tibial angle; mMDTA, mechanical medial distal tibial angle; mMPTA, mechanical medial proximal tibial angle.

Given these similarities and differences to other breeds, without an apparent pattern, it was not possible to reject or accept the null hypothesis.

Mean tibial plateau angle (TPA), which can be calculated from mean mCaPTA, has been widely investigated in dogs with or without cruciate ligament disease (►**Table 1**). Although there is conflicting evidence, previous literature has suggested that a steeper TPA may predispose to cruciate disease.[13,18,19,22,23] The mean TPA in Dachshunds in this study was reported to be 14.6 ± 3.7. This value is notably smaller than similar sized dogs which is interesting given it is uncommon for Dachshunds to be diagnosed with cruciate ligament disease.[21]

There was also a wide variation in reported normal mCrDTA in the literature (►**Table 1**) with the mean mCrDTA in Dachshunds falling within these reported values. This variation between breeds highlights the difference in joint reference angles between breeds—particularly in the sagittal plane and emphasizes the importance of establishing breed specific joint reference angles.

Studies reporting reference angles for other joints have utilized ICC to determine agreement.[24–26] Many studies have used the same methodology to establish normal tibial joint reference angles in the frontal and sagittal plane in different breeds; however, we assessed multiple measurements from multiple observers for this methodology and reported the ICC.[8–10,27,28] Intra-observer agreement was demonstrated to be excellent in the frontal plane and good to excellent in the sagittal plane, supporting the use of this methodology for measurement of mechanical tibial joint angles in the frontal plane.

Although the intra-observer agreement was good to excellent for all values, this was not the case for inter-observer agreement, particularly in the sagittal plane. Wide CI were present when comparing measures between observers for mMDTA, mCaPTA and mCrDTA. Despite the inclusion of adequate case numbers to reach appropriate power for frontal plane evaluation, it is likely the ICC and standard deviation would improve with a larger sample size, particularly in the sagittal plane. Previous publications have reported joint reference angles using smaller sample sizes than used in this study.[7,17,29,30] Further work on a larger population and additional observers would be required to increase our confidence in these secondary findings. Agreement statistics could also be improved with three or more observers.[14]

Tibial plateau angle has previously been shown to have good inter-observer agreement by some authors; however, differing breed morphology has been suggested to be responsible for variation seen.[20,31–33] However, other studies have suggested wider inter-observer variability in TPA measurements of 4.8 degrees, where an effect of observer experience was also identified.[32] Additionally, when TPA moves toward being very high or low, an increase in error is seen, which may be relevant to the low mCaPTA in Dachshunds. The subjectively high variability in tibial conformation, particularly the tibial eminences, and subsequent difficulty in identification of specified landmarks could explain the wide CI observed.[32] It is conceivable that all of these factors could contribute to the wide CI seen within the ICC. A computed tomographic assessment of joint reference angles may reduce some of these issues and could be considered in the future, but is likely not to be as widely applicable as radiographic measurements.[16,26]

The mCrDTA had a poor to good inter-observer agreement as assessed by ICC. Similar to mCaPTA, chondrodystrophic morphology may have hampered landmark identification, for example accurate identification of distal intermediate tibial ridge. Alternatively, it would be possible for a rotational abnormality to be present within the distal tibia complicating identification of the distal landmarks, while radiographs still conform to the confines of the generally accepted definition of an appropriately positioned lateral view. Previous work has shown that minor rotation or torsion along the long axis of the tibia (up to 50%) does not affect measurements in the frontal plane.[8] However, the authors are unaware of investigations of the effect of torsion on sagittal plane joint reference angles.

Dachshunds in this study were categorized into groups based on the reason for the radiographic study, such that joint reference angles could be compared between these groups to ensure no underlying bias was present. Differences were seen in mCaPTA between the groups presenting for non-tibial fractures and for other reasons. Although this could be a type 1 statistical error, despite small sample size (categorizing the Dachshunds by presenting complaint resulted in four relatively small groups), this finding was more likely due to the aforementioned variability in measurements in the sagittal plane. The lack of difference between all other groups at all other joint reference angles supports the homogeneity of data.

Potential limitations of this study include the selection of anatomically normal tibiae. Due to the retrospective nature of the study, it was not possible to perform an orthopaedic examination on subjects and so clinical records were relied upon to ensure no clinical lameness or deformity was present. Radiographic positioning and exposure, while assessed as appropriate, could not be standardized. This limitation was minimized by excluding inappropriately positioned radiographs. Despite this, minor torsional deformities may have been present and computed tomography is recommended over radiography to assess for the presence of torsion.[33,34] Using computed tomography in conjunction with, or as an alternative to radiographs to account for this may be considered. However, previous studies measuring the impact of minor radiographic torsion or rotation have evidenced that no significant impact is made on the proximal and distal tibial mechanical joint angles in the frontal plane[8]

In conclusion, this study has established normal tibial joint reference angles in Dachshunds. These data provide a breed standard for diagnosis and magnitude of varus and valgus deformity in Dachshunds, in addition to aiding planning for correction in clinical cases of pes varus, particularly in bilateral presentations. The methodology for measuring tibial joint angles has been assessed and found to be reliable and repeatable, particularly in the frontal plane. Further research is proposed in Dachshunds with pes varus to understand the degree of deformity that requires surgical intervention.

Authors' Contributions
C.B. contributed to acquisition of data and data analysis and interpretation and partly wrote the manuscript. A.P. contributed to the conception of the study, study design, acquisition and interpretation of data and partly wrote the manuscript. E.K. and D.C. identified suitable cases and contributed to the manuscript. H.P. contributed to data analysis and interpretation. R.M., B.M. and M.P. contributed to the conception of the study and contributed to the manuscript. All authors revised and approved the submitted manuscript and are publically accountable for relevant content.

Conflict of Interest
None declared.

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