Computed tomographic evaluation of femoral and tibial conformation in English Staffordshire Bull Terriers with and without congenital medial patellar luxation

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Keywords

Musculoskeletal imaging, orthopaedic disorders, femoral conformation, tibial conformation, patella luxation, computed tomography

Summary

Objective: To compare hindlimb conformation of English Staffordshire Bull Terriers with and without medial patellar luxation using computed tomography.

Methods: Hindlimb computed tomography (CT) was performed on six English Staffordshire Bull Terriers with grade II or III medial patellar luxation, and six without medial patellar luxation. Inclination angle, femoral condyle trochanteric angle, anteversion angle (AA), distal anteversion angle (DAA), proximal anteversion angle (PAA), femoral varus angle (FVA), tibial valgus angle (TVA), and tibial torsion angle (TTA) were measured. Student's T-test was conducted to compare normal limbs to limbs with medial patellar luxation, all limbs of dogs with medial patellar luxation to limbs of the control group, and medial patellar luxation affected limbs (normal limbs of unilaterally affected dogs excluded) to the control group. P-values less than 0.05 were considered significant.

Results: Two dogs with medial patellar luxation were only affected unilaterally. Limbs of English Staffordshire Bull Terriers with medial patellar luxation had significantly diminished AA and DAA, in addition to decreased TVA. These differences were similar regardless of how the unaffected limbs from affected dogs were treated in our analysis.

Discussion and conclusion: Medial patellar luxation in this population of English Staffordshire Bull Terriers was characterized by a decrease in femoral anteversion, external rotation of the femoral diaphysis, and decreased tibial valgus. These findings may help inform clinical decision making when performing osteotomy for treatment of medial patellar luxation in this breed.

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Introduction

Medial patellar luxation is a common orthopaedic disorder of dogs, which results from a medially directed vector force on the patella. The line of action of the patella is determined by the alignment of the quadriceps femoris muscle group, originating from the ilium in the case of the rectus femoris and the proximal femur in the case of the vasti muscles, the patella, and the patellar ligament and its insertion onto the tibial tuberosity (1, 2). Any malalignment of these components will result in a medial force on the patella and decrease patellar stability. Other stabilizers of the patella include the medial and lateral trochlear ridges, the medial and lateral cartilaginous processes, and the femoropatellar ligaments.

Several features of skeletal morphology of the hip, femur and stifle joint have been suggested or proven to be associated with medial patellar luxation, including coxa vara and valga, diminished angle of anteversion, external femoral torsion, proximal tibial valgus, and internal tibial torsion (3, 4). It is not known if these changes are a primary cause of or a secondary result of medial patellar luxation; it is likely that they represent both a cause and effect (4). Given the spectrum of sizes and conformations that exist across the many breeds of dogs, establishing normal values that apply to all dogs is difficult. Previous studies have evaluated normal ranges for many indices of skeletal conformation in either cohorts of normal dogs of varying breeds or cohorts of normal dogs of one

Figure 1 The angle of inclination (AI) was defined as the angle formed between the axis of the femoral neck and the axis of the femoral diaphysis.

Figure 2 The anatomical lateral distal femoral angle (aLDFA) was defined as the angle created between the anatomical axis of the proximal diaphysis and the transcondylar axis.

particular breed; few studies have so far compared dogs with and without medial patellar luxation of one particular breed, and thus far none have evaluated large breed dogs (5–18). In our practice, the English Staffordshire Bull Terrier appears to be commonly affected with medial patellar luxation. This breed has a characteristic bow-legged stance, which the authors assume represents an underlying conformational abnormality of the femur, tibia, or both together.

Measurements may be made on either conventional radiographs or by using computed tomography (CT) and multiplanar reconstructions (CT-MPR). Computed tomography is less susceptible to positional variation than conventional radiography for measurement of most indices of skeletal conformation. Precise qualification and quantification of skeletal abnormalities theoretically allows for more accurate realignment of the quadriceps mechanism, by allowing planning for correction of the deformity or deformities thought to be most responsible for the quadriceps malalignment.

The aim of this study was to evaluate and compare the femoral and tibial morphology in a population of English Staffordshire Bull Terriers with and without medial patellar luxation. Our hypothesis was that dogs with medial patellar luxation would have multiple conformational differences of the femur and tibia compared to clinically normal dogs, with a particular increase in distal femoral varus.

Materials and methods

Twelve English Staffordshire Bull Terriers were prospectively recruited into the study between March 2012 and November 2013, consisting of six dogs affected with either unilateral or bilateral medial patellar luxation and six clinically normal dogs. Clinical evaluation was performed by either a board-certified specialist in small animal surgery (KV) or a senior resident in small animal surgery (MN). Clinically normal dogs were defined as those with no abnormalities on orthopaedic examination and a stable patella, both when conscious and when under general anaesthesia. The severity of medial patellar luxation was graded according to the Singleton criteria and patients with a grade 2/4 or higher were included (19). Patients were excluded from the study if other stifle disease was present, such as cranial cruciate ligament rupture. Institutional animal ethics approval was granted for this study.

Following premedication with either a combination of acepromazine (0.05 mg/kg IM) and methadone (0.3 mg/kg IM) or dexmedetomidine (0.003 mg/kg – 0.01 mg/kg IM) and butorphanol (0.3 mg/kg), anaesthesia was induced with propofol to effect and maintained on isoflurane in 100% oxygen. Bilateral hindlimb computed tomography was performed using a 16 slice helical scanner[a] with 0.8 mm slice thickness. For affected dogs, this CT was performed as part of routine evaluation prior to surgical correction. For control patients, this CT was performed whilst undergoing another procedure that required general anaesthesia. Owner consent was obtained prior to the scans of these unaffected dogs. Dogs were positioned in dorsal recumbency with the hindlimbs extended caudally and taped together such that the femurs were parallel to each other. As measurements across joints were not to be obtained, and images were to be manipulated post-acquisition to view in the ideal plane, joint angles were not rigidly standardized. Multiplanar reconstructions were created from the axial images using a commercial DICOM viewer[b].

Eight measurements were obtained from each hindlimb. The multiplanar reconstructions were manipulated in such a manner that the ideal projection was simulated for each measurement. The measurements taken were as follows: the angle of inclination of the femoral neck (AI), the anatomical lateral distal femoral angle (aLDFA), the femoral trochanteric angle

a Brilliance 16-Slice: Phillips, Amsterdam, Netherlands
b OsiriX: Pixmeo SARL, Bernex, Switzerland

(FCT), the angle of anteversion of the femoral neck (AA), the distal anteversion angle (DAA) and proximal anteversion angle (PAA), overall tibial valgus (TV), and tibial torsion (TT).

The AI was measured from a frontal plane reconstruction according to the Hauptman B method, as previously described using CT (5, 14). The multiplanar reconstruction of the femur was oriented such that the frontal plane and sagittal plane were parallel to the long axis of the diaphysis, and the femoral condyles were symmetrical; thus a true frontal plane aligned to the diaphysis was found. The AI represents the angle formed between the axis of the femoral neck and the anatomical axis of the proximal femoral diaphysis (▶Figure 1) in this frontal plane reconstruction, both measured on a maximum intensity projection thick enough to view the femoral head, neck, and diaphysis. The axis of the femoral neck was created by points marking the centre of the femoral head and the midpoint of the femoral neck; the anatomical axis of the proximal femoral diaphysis was created by points marking the midpoint of the diaphysis a third and a half the distance down the diaphysis.

The aLDFA was also measured from the same frontal plane reconstruction of the femur, as previously described (9). The aLDFA was defined as the angle created between the anatomical axis of the proximal diaphysis, as previously created and the transcondylar axis (▶Figure 2). The transcondylar axis was created by points representing the most distal medial and lateral femoral condyles. The aLDFA was measured on a maximum intensity projection thick enough to view the femoral diaphysis and condyles.

From the same multiplanar reconstruction in which the frontal plane was viewed, the transverse plane was used to measure the FCT, AA, DAA and PAA. In this plane the entire diaphysis of the femur could be viewed as a straight cylinder by scrolling through sequential images. The FCT was measured as previously described using CT-MPR (14). This was defined as the angle formed between the transcondylar axis and a proximal line connecting the greater and lesser trochanters (▶Figure 3). A maximum intensity projection several centimetres thick was created, and the transcondylar axis was found using points representing the most caudal aspects of the medial and lateral femoral condyles; the grid lines visible on the imaging software were then set at this axis. The images were then scrolled through until the greater and lesser trochanters were visible in one slice, and a line joining those two points was created.

The AA was defined as the angle created between the transcondylar axis and a line representing the axis of the femoral neck (▶Figure 4), measured in the same manner as the FCT. The AA was further subdivided into the DAA and PAA (14). The DAA was measured as the angle connecting the transcondylar axis and a line from the lesser trochanter to the point of intersection of the transcondylar axis with the previous line through the femoral neck (▶Figure 5). This angle represents the amount of anteversion between the lesser trochanter and the condyles, which can be thought of as synonymous with diaphyseal torsion. The PAA was defined as the difference between the overall anteversion and the distal anteversion, and this represents the contribution of the femoral head and neck to the overall amount of anteversion (▶Figure 6).

The TV was assessed on a frontal plane reconstruction of the tibia. The multiplanar reconstruction was manipulated so that the frontal plane intersected the caudal most points of the tibial condyles and the caudal aspect of the distal tibia. A maximum intensity projection of the thickness of the tibia was created in this plane so that both the proximal and distal joint surfaces could be viewed in their entirety to accurately identify the joint line. The TV was defined as the angle created between the proximal and distal joint lines (▶Figure 7). This is a

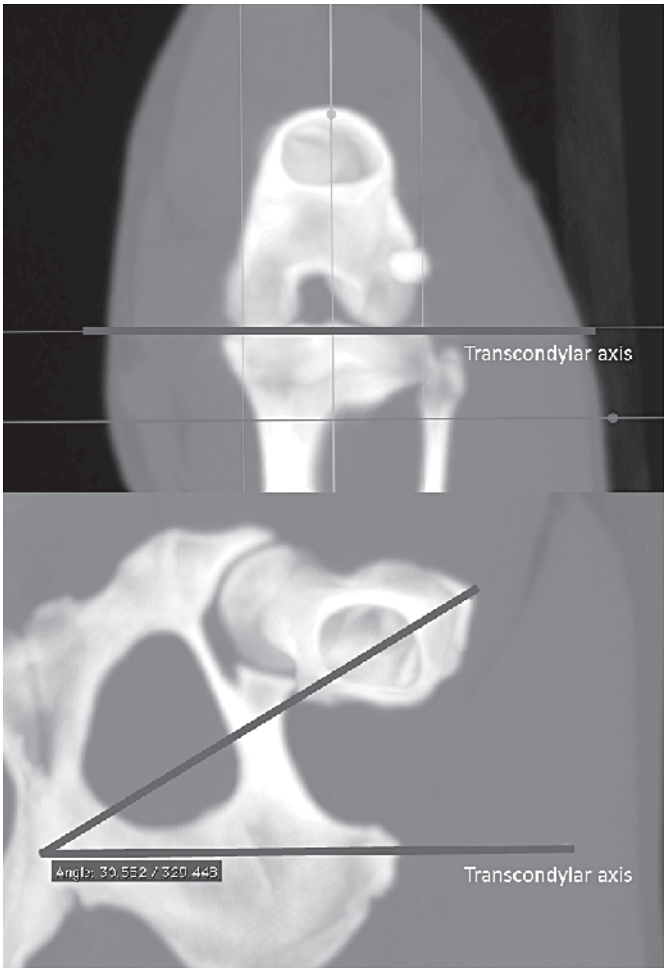

Figure 3 The femoral trochanteric angle (FCT) was defined as the angle formed between the transcondylar axis and a proximal line connecting the greater and lesser trochanters.

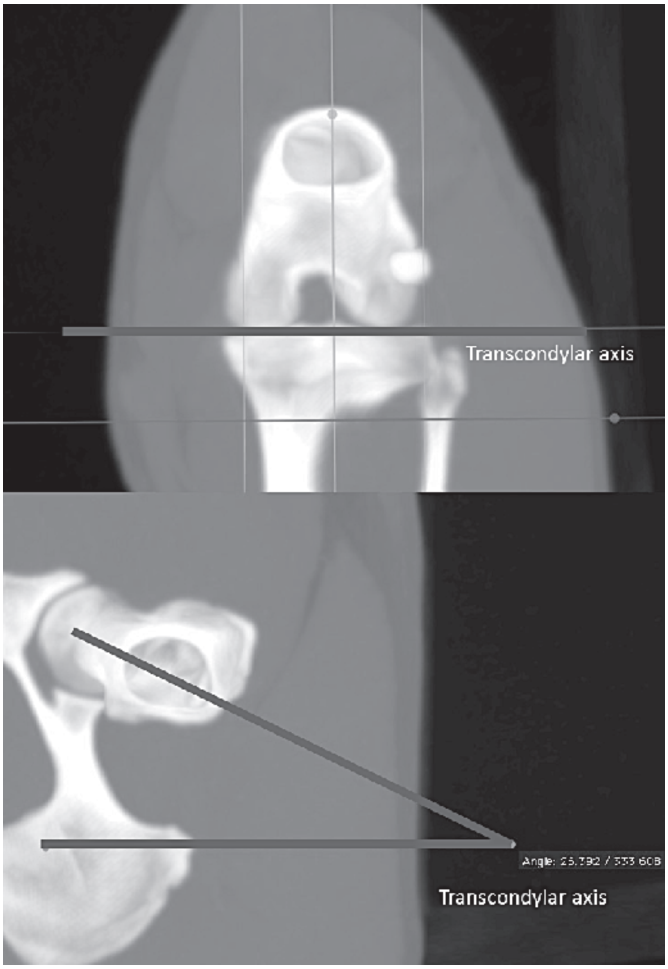

Figure 4 The angle of anteversion (AA) was defined as the angle created between the transcondylar axis and a line representing the axis of the femoral neck.

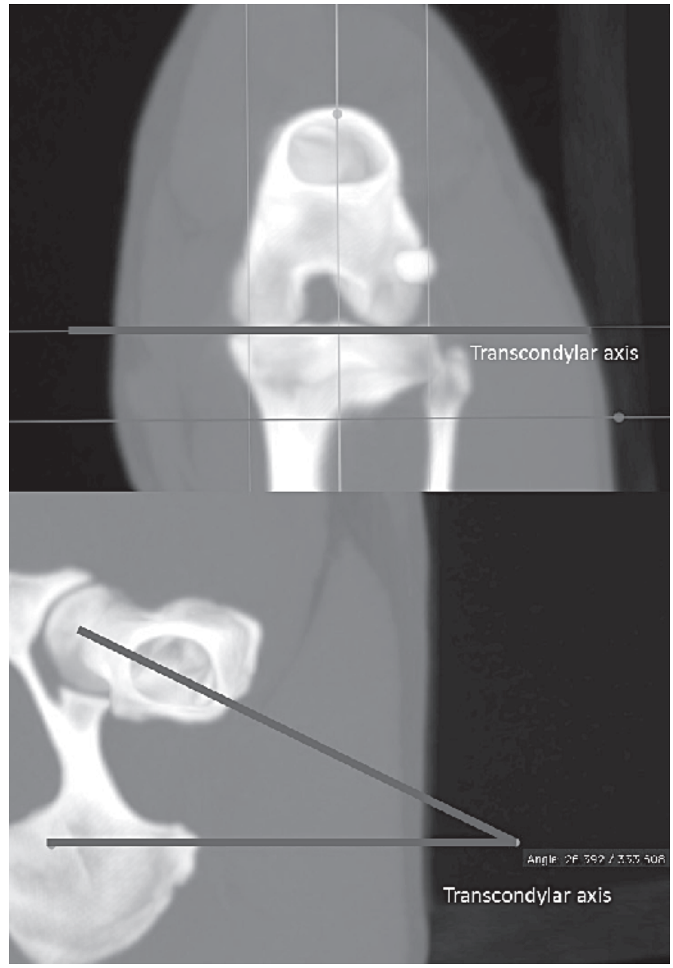

Figure 5 The distal angle of anteversion (DAA) was defined as the angle connecting the transcondylar axis and a line from the lesser trochanter to the point of intersection of the transcondylar axis with the axis of the femoral neck.

summation of the mechanical medial proximal tibial angle (mMPTA) and mechanical medial distal tibial angle (mMDTA) as previously described (10).

The TT was assessed on an axial reconstruction of the tibia, which was the transverse plane created by aligning the frontal plane as described for TV. Using the caudal condylar axis to the distal cranial tibial axis (CdC-CnT) technique as previously described, this was defined as the angle created between the caudal transcondylar axis proximally, and the cranial surface of the tibia distally (►Figure 8) (7). A maximum intensity projection of several centimetres in thickness was created , and the caudal transcondylar axis was created by points representing the caudal most aspect of the medial and lateral tibial condyles. The grid lines visible on the imaging software were then set at this axis. The images were then scrolled through until the distal tibia was visible and a line parallel to the cranial surface was created.

Data analysis

Three separate analyses were performed for comparison of measurements between groups to account for the fact that the normal limbs from unilaterally affected dogs may share some characteristics with the affected limbs. Firstly, the measurements from the control dogs were compared to those from the clinically affected dogs. Secondly, the normal limbs from affected animals were grouped with the limbs from the control dogs, and measurements from all normal limbs were compared to those from affected limbs. Thirdly, the normal limbs from affected dogs were excluded from analysis, and the measurements from control dogs were compared to affected limbs.

The measurements were tested for normality with the Shapiro Wilk test. All measurements were normally distributed, with the exception of those for tibial valgus. Tibial valgus was compared with the Mann-Whitney U test, and all other measurements were compared with Student's T-Test. The level of significance was set at less than or equal to 0.05.

Results

Of the six affected dogs, two were unilaterally affected and four bilaterally affected, giving a total of 10 affected limbs. Twelve

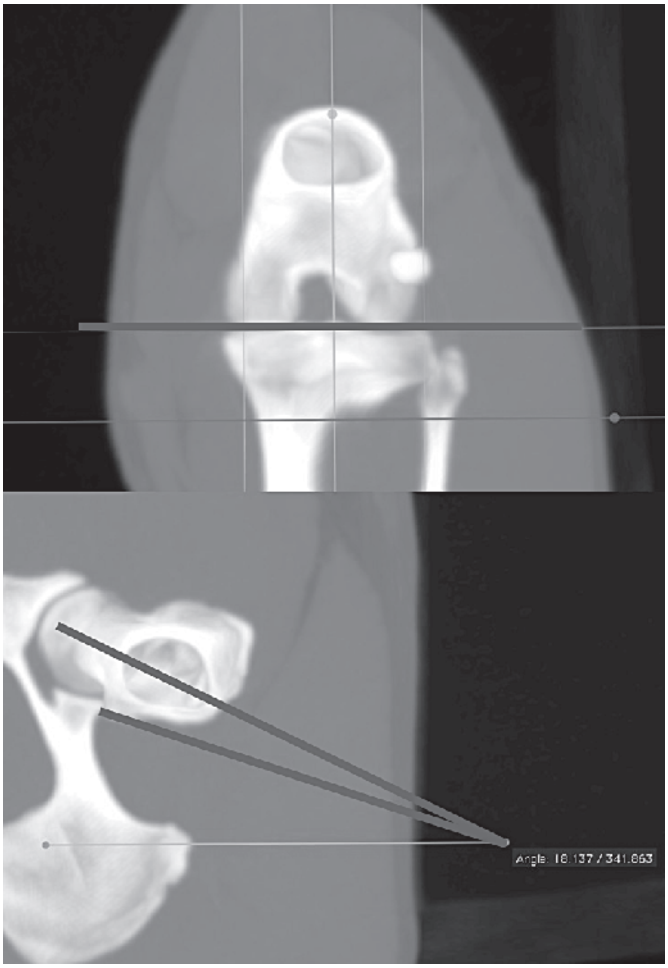

Figure 6 The proximal angle of anteversion (PAA) was defined as the difference between the angle of anteversion (AA) and the distal angle of anteversion (DAA).

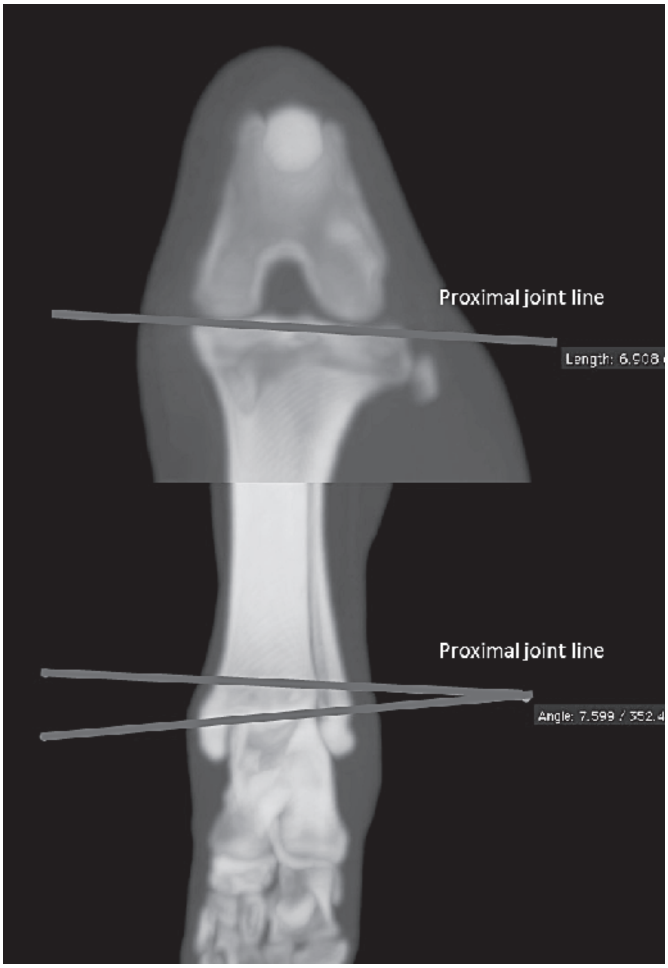

Figure 7 Tibial valgus (TV) was defined as the angle created between the proximal and distal joint lines in the frontal plane.

limbs were from the six unaffected dogs, and two more unaffected limbs were from unilaterally affected dogs. Of these, two were classified as having grade 2/4 medial patellar luxation, and eight were classified as having grade 3/4 medial patellar luxation. There were no differences between the two groups with regards to age or weight; the unaffected animals had a median age of seven years and a mean weight of 18.4 kg, while the affected animals had a median age of three and a mean weight of 23.1 kg. There were three males and three females in each group.

The measurements from control dogs compared with affected dogs are summarized in ►Table 1. Affected dogs were found to have significantly less overall femoral anteversion and less distal anteversion than control dogs. Affected dogs had an AA of 21.9 degrees, compared to 26 degrees in unaffected dogs. The DAA was 14.9 degrees in affected dogs compared to 17.9 degrees in unaffected dogs. Affected dogs also had a significantly lesser degree of tibial valgus, with 8.9 degrees of TV compared to 11.8 degrees in control dogs.

The findings for when the two unaffected limbs from unilaterally affected dogs were considered normal and grouped with the control dogs are summarized in ►Table 2. The findings of decreased overall and distal anteversion in affected limbs remained. Overall anteversion was 21.8 degrees in affected limbs and 25.6 degrees in unaffected limbs, while distal anteversion was 14.8 degrees compared to 17.6 degrees. Femoral varus in affected limbs showed a trend to be increased compared to unaffected limbs, with 98.5 degrees of aLDFA in affected limbs compared to 96.6 degrees in unaffected limbs; this however was not statistically significant. Interestingly only three affected limbs and one unaffected limb had femoral varus exceeding 12 degrees.. Interestingly, only three affected limbs and one unaffected limb had femoral varus exceeding 12 degrees.

The results for when the two unaffected limbs from unilaterally affected dogs were excluded from analysis are summarized in ►Table 3. There remained significantly less overall (21.8 degrees) and distal anteversion (14.8 degrees) in the affected limbs than in the unaffected limbs (26 degrees and 17.9 degrees respectively) ($p = 0.012$ and $p = 0.022$, respectively). Tibial valgus was also significantly less in affected limbs (8.3 degrees) compared to the unaffected limbs (11.8 degrees) ($p = 0.008$).

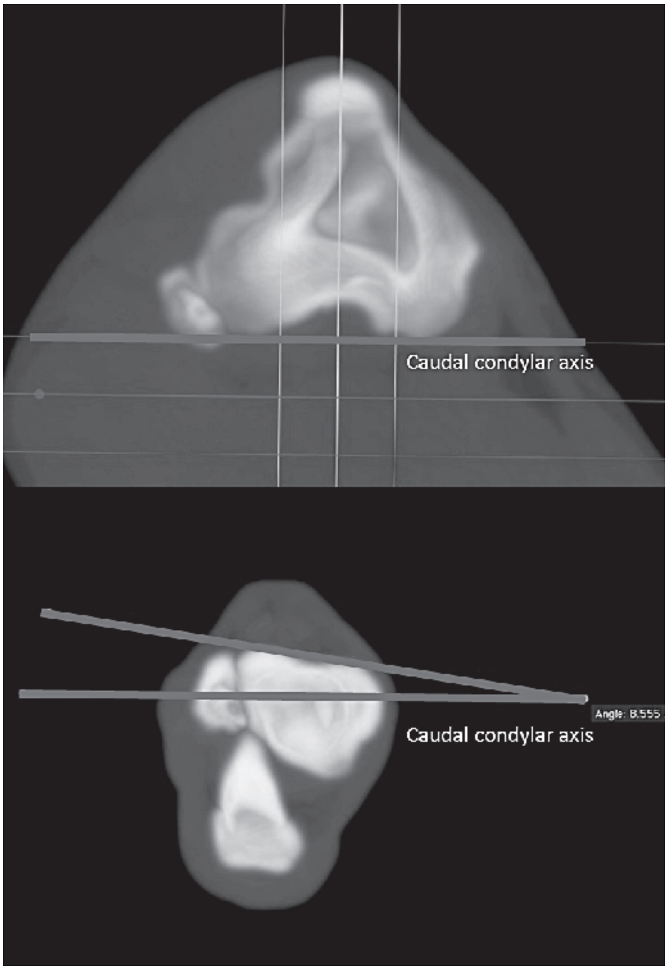

Figure 8 Tibial torsion (TT) was defined as the angle created between the caudal transcondylar axis proximally and the cranial surface of the tibia distally.

When subjectively comparing the angles to historical measurements obtained from CT scans in other dogs, it appears that both affected and unaffected English Staffordshire Bull Terriers have higher AI, higher FCT, and lower DAA than other dogs studied previously (▶Table 4).

Discussion

This study found that medial patellar luxation in this population of English Staffordshire Bull Terriers is characterized by a relative retroversion of the femur, apparently as a torsional malformation along the femoral diaphysis (DAA), and decreased tibial valgus. Our hypothesis that femoral varus would be increased in the population of English Staffordshire Bull Terriers with medial patellar luxation had to be rejected.

The finding of a reduced AA, attributable to diaphyseal torsion, may have implications when planning surgical correction of medial patellar luxation in such cases. A reduction in the AA, whether at the level of the femoral neck, along the diaphysis, or both, will theoretically result in an external rotation of the femur at the level of the hip joint or the femur per se, with subsequent lateral displacement of the femoral trochlea, and compensatory angulation of the distal limb.

The normal values for AA in the dog, as measured via CT in various studies, has been reported as 28.0–33.93, 19.6, 30.4–30.5, and 19.8 degrees; using MRI the AA has been reported as 7.6 degrees (4, 9, 11, 18, 20). In our population, the unaffected dogs had a mean AA of 26 degrees. The wide range of reported values in normal animals probably reflects a difference between individual dog breeds, and the large difference between the CT and MRI measurement probably reflects a difference in the identification of anatomical landmarks between imaging modalities. A reduction in AA with medial patellar luxation has been documented in several studies; the affected dogs in our study had a mean AA of 21.8–21.9 degrees, which compares with previously reported values of 20.9 and 9.6–16.6 degrees (18, 21). By differentiating PAA and DAA, it can be seen that the majority of the difference between normal dogs and affected limbs in this population is as a result of torsion along the diaphysis rather than a difference in the angle of insertion of the femoral neck. In Labrador Retrievers the DAA has been measured as 20.4–25.0 degrees, as compared to values of 14–8–17.9 degrees found in our study subjects, suggesting a more external diaphyseal torsion in our population of English Staffordshire Bull Terriers (14). As it is difficult to determine PAA and DAA on radiographs unless a perfect axial projection is obtained, use of CT allows for more precise measurement for planning purposes.

In both affected and unaffected limbs, we also found a seemingly higher angle of inclination (135.14–136.72 degrees) than has been reported in previous CT studies evaluating Labrador Retrievers (130–136 degrees), Toy Poodles (116.8–118.3 degrees), and a variety of breeds (130 degrees). However the AI was not significantly different between groups in our study, suggesting a 'normal' degree of coxa valga in this population, especially when compared to smaller breed dogs such as Toy Poodles (14, 18, 21). To the authors' knowledge, there have been no studies performed thus far to directly compare CT and radiographic determination of AI. The method of measurement of AI is important when performing comparisons between studies. Using the method of Montavon and colleagues, a normal range of 140.5–156.5 degrees is commonly cited; however using the Hauptman B technique, as has been performed in our study and the aforementioned CT studies, the reported radiographic values are 129.4, 126.5–131.3, 132–137, and 136.33 degrees (5, 6, 12, 14, 16). Variations in positioning for radiographic evaluation would be expected to influence the perceived AI, as has been reported when measuring distal femoral varus (13). The association of AI with medial patellar luxation is unclear. Coxa valga has been associated with medial patellar luxation in a large retrospective study of dogs with medial patellar luxation; this study employed the method of Montavon and colleagues for AI measurement, thus direct comparison between values is not possible (22). Coxa valga may create an abduction of the femur with a resultant lateral displacement of the trochlear groove, increasing the medial vector force on the patella and increasing the risk of luxation.

Whilst our results for AA were not less than some previously reported values, in our opinion the combination of mild retroversion in the affected dogs and coxa valga in the overall population of dogs suggests a primarily abducted and retroverted coxofemoral joint, with subsequent lateral displacement of the femoral trochlea that is more significant than would be found with either of these abnormalities alone.

Distal femoral varus is a malformation that is commonly seen in patients with medial patellar luxation, and correction of femoral varus greater than 10–12 degrees (aLDFA 100–102 degrees) has been suggested as a primary method of realigning the quadriceps mechanism (15, 16, 18, 23). Of note in our population, and contrary to our hypothesis, excessive femoral varus was infrequently seen in either affected or unaffected dogs, with only four limbs (1 control from an unaffected dog, and 3 affected limbs) having femoral varus measurements in excess of 12 degrees.

The tibial valgus measurement in this study is a combined measurement of the mechanical medial proximal tibial angle (mMPTA) and the mechanical medial distal tibial angle (mMDTA) as previously described separately (10). The two measurements were combined in this study into one angle for simplicity; however this does not allow for determination of the precise location along the bone of any deformity, or for direct comparison to other studies. We have however shown a decrease in the amount of overall valgus in the tibia in affected patients compared to unaffected patients; this can be thought of as a relative tibial varus which may be a compensation

Table 1 Affected dogs versus unaffected dogs.

Measurement	Mean ± SD control	Mean ± SD affected	p-value
AI	136.72 ± 8.27	135.14 ± 7.27	0.62
FCT	30.68 ± 4.56	33.38 ± 3.79	0.13
AA	26.03 ± 3.35	21.94 ± 3.67	0.0092
PAA	7.94 ± 1.39	6.83 ± 2.45	0.19
DAA	17.92 ± 3.16	14.93 ± 2.32	0.015
aLDFA	96.18 ± 4.06	98.62 ± 3.23	0.12
TV	11.80 ± 3.11	8.87 ± 2.43	0.02
TT	6.82 ± 5.60	5.47 ± 4.88	0.64

AA = angle of anteversion; AI = angle of inclination of the femoral neck; aLDFA = anatomical lateral distal femoral angle; DAA = distal angle of anteversion; FCT = femoral trochanteric angle; PAA = proximal angle of anteversion; SD = standard deviation; TT = tibial torsion; TV = tibial valgus.

Table 2 Affected limbs versus unaffected limbs.

Measurement	Mean ± SD control	Mean ± SD affected	p-value
AI	136.34 ± 8.29	135.35 ± 7.08	0.76
FCT	30.79 ± 4.24	33.76 ± 3.87	0.094
AA	25.56 ± 3.37	21.76 ± 3.94	0.019
PAA	7.86 ± 1.40	6.73 ± 2.62	0.19
DAA	17.56 ± 3.05	14.83 ± 2.54	0.03
aLDFA	96.59 ± 3.89	98.54 ± 3.55	0.22
TV	11.75 ± 3.04	8.30 ± 1.93	0.0064
TT	7.24 ± 5.74	4.51 ± 3.95	0.29

AA = angle of anteversion; AI = angle of inclination of the femoral neck; aLDFA = anatomical lateral distal femoral angle; DAA = distal angle of anteversion; FCT = femoral trochanteric angle; PAA = proximal angle of anteversion; SD = standard deviation; TT = tibial torsion; TV = tibial valgus.

Table 3 Affected limbs versus unaffected dogs.

Measurement	Mean ± SD control	Mean ± SD affected	p-value
AI	136.72 ± 8.27	135.35 ± 7.08	0.69
FCT	30.68 ± 4.46	33.76 ± 3.87	0.1
AA	26.03 ± 3.35	21.76 ± 3.94	0.012
PAA	7.94 ± 1.39	6.73 ± 2.62	0.18
DAA	17.92 ± 3.16	14.83 ± 2.54	0.022
aLDFA	96.18 ± 4.06	98.54 ± 3.55	0.17
TV	11.8 ± 3.11	8.3 ± 1.93	0.008
TT	6.82 ± 5.60	4.51 ± 3.95	0.41

AA = angle of anteversion; AI = angle of inclination of the femoral neck; aLDFA = anatomical lateral distal femoral angle; DAA = distal angle of anteversion; FCT = femoral trochanteric angle; PAA = proximal angle of anteversion; SD = standard deviation; TT = tibial torsion; TV = tibial valgus.

Table 4 Comparison with previously published computed tomography studies.

Measurement	Mean ± SD limbs from unaffected dogs	Mean ± SD affected limbs	Previously reported CT values
AI	136.72 ± 8.27	135.35 ± 7.08	130–136 (Labrador Retriever) (14) 116.8–118.3 (Toy Poodle) (18) 130 (21)
FCT	30.68 ± 4.46	33.76 ± 3.87	24.8–29.7 (Labrador Retriever) (14)
AA	26.03 ± 3.35	21.76 ± 3.94	28.0–33.93 (Labrador Retriever) (14) 19.6 (9) 30.4–30.5 (11) 19.8 (Toy Poodle) (18) 26.6 (24)
PAA	7.94 ± 1.39	6.73 ± 2.62	7.6–8.9 (Labrador Retriever) (14)
DAA	17.92 ± 3.16	14.83 ± 2.54	20.4–25.0 (Labrador Retriever) (14)
aLDFA	96.18 ± 4.06	98.54 ± 3.55	98.8 (9) 90.3 (normal), 89.5 (grade II MPL), 108.1 (grade IV MPL) (Toy Poodle) (18) 96.2 (24)
TV	11.8 ± 3.11	8.3 ± 1.93	
TT	6.82 ± 5.60	4.51 ± 3.95	4.5 (7)

AA = angle of anteversion; AI = angle of inclination of the femoral neck; aLDFA = anatomical lateral distal femoral angle; CT = computed tomography; DAA = distal angle of anteversion; FCT = femoral trochanteric angle; MPL = medial patellar luxation; PAA = proximal angle of anteversion; SD = standard deviation; TT = tibial torsion; TV = tibial valgus.

for the small amount of relative coxa valga and external femoral torsion, particularly where an increased AI is not compensated for by distal femoral varus. The combined tibial valgus in a population of Labrador Retrievers was a mean of 9.3 degrees in the aforementioned study which compares similarly to the results in our study, implying that neither normal nor affected English Staffordshire Bull Terriers have an excessive relative tibial varus or valgus (10).

Computed tomography assessment of tibial torsion has been demonstrated to be more accurate than using plain radiographs (8). A previous study assessed crural torsion, incorporating the lateral malleolus in their measurements, rather than tibial torsion due to the ability to consistently identify landmarks (24). Tibial landmarks for assessment of torsion were readily identifiable in this study so the CdC-CnT axes as previously described were employed; however this makes comparison with other studies difficult (7). In Yorkshire Terriers with medial patellar luxation, internal torsion of the tibia was found to increase with increasing grade of medial patellar luxation (17). A normal value for CdC-CnT using CT has been reported as 4.5 degrees of internal torsion of the cranial aspect of the distal tibia relative to the caudal aspect of the condyles proximally, similar to our results of 4.5–7.2 degrees, which were not different between groups (7). Given that external femoral torsion was seen, it is interesting that a compensatory internal tibial torsion was not also found. Given the minor variation in results depending on how the unaffected limbs of unilaterally affected dogs were treated, it is logical that these limbs cannot be classified as truly normal. This is of importance when planning surgical correction of medial patellar luxation, as the contralateral limb of a unilaterally affected dog is often used to decide upon the values to which the abnormal limb should be surgically corrected. However, our study did not have sufficient numbers of these limbs to evaluate them statistically as a group on their own. It seems prudent to exclude these limbs from analysis when trying to determine the difference between a normal limb and one affected by medial patellar luxation.

We acknowledge several limitations in this study. The small number of subjects may be responsible for type II error when comparing some measurements, and given the large range in some measurements this is likely. As it was not possible to reduce the patella into the femoral trochlea in all cases during positioning for the CT scans, the investigators were not blinded to the clinical status of each dog. Certain measurements were not performed in this study. Measurements across joints, such as the Q angle, were not performed due to the difficulty in ensuring repeatable limb positioning between patients. Difficulty in accurately reproducing some anatomical landmarks in these dogs also precluded other measurements, such as the position of the tibial tuberosity and the depth of the trochlea. We also did not perform any evaluation of the intra-observer or inter-observer variation in this study, a factor which may potentially bias these results. However, previous studies have evaluated the intra-observer and inter-observer variation for the measurement of AA, aLDFA, mMPTA, and crural torsion angle (CTA – similar to our TT) and found good repeatability and reproducibility (24). Good agreement between observers was found in another study evaluating tibial torsion, again assessed in a slightly different manner to ours (17).

In summary, medial patellar luxation in this population of English Staffordshire Bull Terriers was characterized by a decrease in femoral anteversion, external rotation of the femoral diaphysis and decreased tibial valgus. The English Staffordshire Bull Terrier appears to have a relative coxa vara when comparing to other breeds in studies employing CT measurements. Our hypotheses that femoral varus would be a major contributor to medial patellar luxation in this population was rejected. These findings may help inform clinical decision making for the treatment of medial patellar luxation in this breed.

Author contributions

Both authors were responsible for the study conception and design, as well as the acquisition, analysis and interpretation of data, and the drafting and revising of the manuscript. Both authors also read and approved the final manuscript.

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Conflict of interest

The authors have no conflicts of interest.

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