# Comparison of Hindlimb Conformation in Cats with and without Medial Patellar Luxation

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## Abstract

**Objectives** Medial patellar luxation (MPL) is the most common developmental cause of hindlimb lameness in cats. The association between femoral and tibial conformation and MPL measured on computed tomography (CT) has not been reported in cats. The aims were to report femoral and tibial conformation in cats with and without MPL and to report normal femoral and tibial angles.

**Methods** Angle of inclination of femoral neck (AI), anatomical lateral distal femoral angle (aLDFA), femoral trochanteric angle (FCT), angle of anteversion of femoral neck (AA), distal and proximal anteversion angle (DAA/PAA), overall tibial valgus (TV), tibial torsion (TT), tibial tuberosity displacement (TTD) and trochlear depth:patellar thickness ratio (T:P) were measured by three observers on CT of cats with and without MPL. Comparisons were made between groups. Inter-observer intraclass correlation coefficient (ICC) was calculated.

**Results** Sixteen cats were recruited: eight control and eight with MPL. The aLDFA, PAA, TT, TTD and T:P were significantly less in cats with high-grade MPL. The AI, FCT, AA, DAA and TV were not significantly different. A high correlation was shown with inter-observer ICC in 33.33% and good correlation in 26.67% when comparing measurements between observers.

**Clinical Significance** This study suggests that cats with high-grade MPL have decreased TT, TTD and T:P and may require tibial tuberosity transposition and femoral trochleoplasty. The PAA, TT and aLDFA were decreased, although clinical significance may vary and these cats may not require correctional osteotomies. Results should be interpreted with caution as high/good levels of inter-observer ICC occurred in less than two-thirds of cases between observers.

**Keywords**
- computed tomography
- corrective osteotomy
- cat
- patellar luxation
- hindlimb conformation



## Introduction

Medial patellar luxation is the most common developmental cause of hindlimb lameness in the cat and is becoming more frequently recognized.[1–3] Clinical signs can vary and include reluctance to jump, vocalization and severe lameness.[1–3] Contrary to dogs, a degree of patellar laxity can be considered normal in the cat.[1,3]

Surgical management of these cases is often derived from techniques in the dog with the main objective of surgery to improve alignment of the quadriceps mechanism and

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improve patellar tracking. However, more recent publications have suggested additional techniques are required, such as a partial patellectomy, based on the unique anatomy in the cat.[4–6] A weak correlation with hip dysplasia and patellar luxation in cats has also been described.[3]

Skeletal deformities have been reported in dogs with patellar luxation with a malalignment of the quadriceps mechanism leading to a medially directed force on the patella and consequently medial luxation.[7–10] Coxa valga, coxa vara, femoral torsion, femoral varus, diminished angle of anteversion and tibial valgus or torsion have all been correlated with medial patellar luxation in dogs.[11,12] Traditional surgical techniques such as tibial tuberosity transposition, femoral trochleoplasty and soft tissue procedures may not be sufficient to prevent luxation in the most severe cases and corrective ostectomies may be required.[1,13–20] In our clinical experience, tibial tuberosity transposition is required less frequently in cats with medial patellar luxation compared to dogs.

Assessment of femoral and tibial deformities is possible through a range of diagnostic imaging modalities but most commonly through radiography or computed tomography (CT).[7–10,21–24] Computed tomography has been shown to be repeatable with good intra- and inter-observer repeatability in dogs.[21] It reduces inherent variability possible with radiographic positioning errors thus increasing accuracy and repeatability.

A recent study investigated the normal anatomical angles of the femur and tibia radiographically in normal cats[25] however, this has not yet been established with CT and the effect of femoral and tibial conformation on patellar luxation has not previously been investigated in the cat. The primary aim of this study was to report and compare femoral and tibial conformation in a population of cats with and without medial patellar luxation. Secondary aims of the paper were to report the normal femoral and tibial angles in a population of normal cats and to assess the repeatability of these CT measurements in cats. Our hypothesis was that there would be no significant difference in femoral and tibial conformation in cats with or without medial patellar luxation.

## Materials and Methods

Cats presenting to Langford Vets Small Animal Referral Hospital (Bristol, United Kingdom) were prospectively recruited into the study between 2019 and 2021. Ethical approval for the study was granted by the University of Bristol Animal Welfare and Ethical Review Body. Cats diagnosed with medial patellar luxation on orthopaedic examination, by either a board-certified specialist in small animal surgery or a supervised resident in small animal surgery, underwent a CT scan as part of the routine assessment of these cases. The degree of patellar luxation was graded 1 to 4 as characterized by the Singleton criteria.[11,26] Other clinical examination findings were also recorded. Owners consented to use of data in this study. Cats with patellar luxation were sedated for CT with a combination of dexmedetomidine (0.005–0.008mg/kg intravenous [IV]) (Dexdomitor, Zoetis, New Jersey, United States) and methadone (0.3mg/kg IV) (Comfortan, Dechra, Shropshire, United Kingdom) or dexmedetomidine (0.005–0.01 mg/kg intramuscular [IM] or 0.005–0.008mg/kg IV) and butorphanol (0.3-mg/kg IM or IV) (Dolorex, MSD Animal Health, Milton Keynes, United Kingdom).

Cats presented to Langford Vets for the management of pelvic trauma were used as a control group. Owners consented to participation in the study. Case management did not differ from routine management of pelvic fracture cases but bilateral hindlimb CT was performed at the same time as CT of the pelvis. A full orthopaedic examination was performed to ensure control cases did not have patellar luxation. Trauma cases were sedated for CT if cardiovascularly stable or anaesthetized. Sedation consisted of a combination of dexmedetomidine (0.005–0.008mg/kg IV) and methadone (0.2mg/kg IV). Premedication for anaesthesia was either a combination of dexmedetomidine (0.003–0.01mg/kg IV) with either methadone (0.1–0.2mg/kg IV) or fentanyl (0.005–0.01mg/kg IV) (Fentadon, Dechra, Shropshire, United Kingdom), or methadone alone (0.2 mg/kg IV). Induction of anaesthesia was performed with either propofol (PropoFlo Plus, Zoetis, New Jersey, United States) or alfaxalone (Alfaxan Multidose, Jurox, Crawley, United Kingdom) to effect, or a co-induction with midazolam (0.2mg/kg IV) (Hypnovel, Roche, Basel, Switzerland) and ketamine (3mg/kg IV) (Narketan 10, Vetoquinol, Northamptonshire, United Kingdom), then maintained on either isoflurane (IsoFlo, Zoetis, New Jersey, United States) or sevoflurane (SevoFlo, Zoetis, New Jersey, United States) in 100% oxygen.

All cats were positioned in sternal recumbency with the hindlimbs extended caudally. Joint angles were not standardized as images were manipulated after being acquired. A 16 slice Siemens CT scanner was used to acquire all images with 0.75 mm slice thickness.

A commercial DICOM viewer (Horos, Maryland, United States) was used to create multiplanar reconstructions (MPR) of each hindlimb. Ten measurements were performed on every femur and tibia including angle of inclination of the femoral neck (AI), anatomical lateral distal femoral angle (aLDFA), femoral trochanteric angle (FCT), angle of anteversion of the femoral neck (AA), distal anteversion angle (DAA) and proximal anteversion angle (PAA), overall tibial valgus (TV), tibial torsion (TT), tibial tuberosity displacement (TTD) and trochlear depth to patellar thickness ratio (T:P) as has previously been described.[7,21,27] Femur and tibia were included for measurements if the whole bone was intact and included in the scan and there was no movement artefact. All ten measurements were performed by three observers: two board-certified specialists in small animal surgery (ABL and SLH) and a resident in small animal surgery (ABE).

### Angle of Inclination of the Femoral Neck

The MPR was manipulated so that the long axis of the femur was parallel to both the frontal and sagittal plane. The frontal plane was used to calculate the AI. The femoral neck axis was created by drawing a line between the centre of the femoral head and the midpoint of the femoral neck. The axis of the proximal femoral diaphysis was created by drawing a line between the midpoint of the femoral diaphysis at the level of

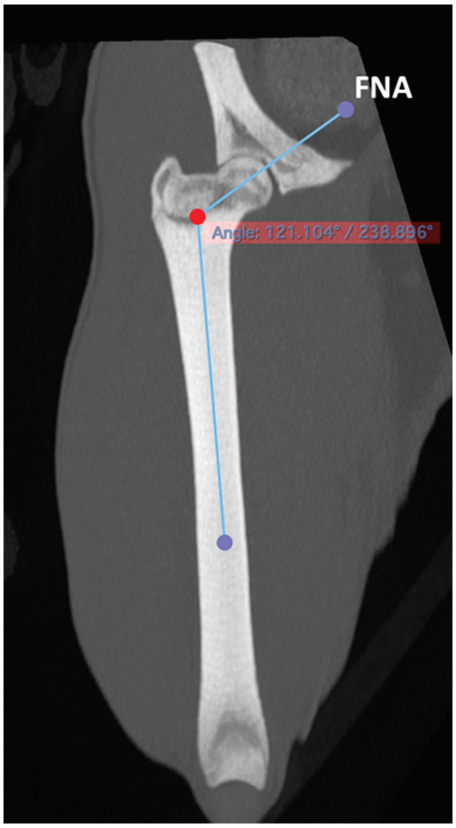


**Fig. 1** Frontal plane computed tomography scan demonstrating measurement of the angle of inclination of the femoral neck (AI). The femoral neck axis (FNA) was drawn between the centre of the femoral head and the midpoint of the femoral neck. The axis of the proximal femoral diaphysis was drawn between the midpoint of the femoral diaphysis at the level of the proximal third of the femoral diaphysis and mid diaphysis. The AI was the angle between these two lines.

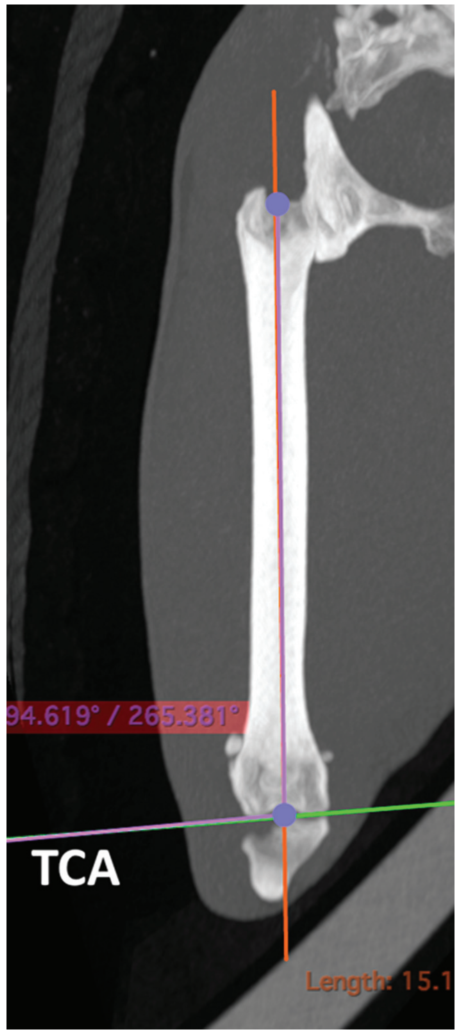


**Fig. 2** Frontal plane computed tomography scan demonstrating measurement of the anatomical lateral distal femoral angle (aLDFA). The transcondylar axis (TCA) was drawn intersecting both the medial and lateral femoral condyles. The aLDFA was measured as the angle between the transcondylar axis and the axis of the proximal femoral diaphysis as measured for angle of inclination of the femoral neck.

the proximal third of the femoral diaphysis and mid diaphysis. The AI was the angle between the femoral neck axis and the anatomical axis of the proximal femoral diaphysis (►**Fig. 1**).

### Anatomical Lateral Distal Femoral Angle

The aLFDA was measured on the same frontal plane MPR used to measure AI. The transcondylar axis was created by drawing a line that intersected both the medial and lateral femoral condyles. The aLDFA was measured as the angle between the transcondylar axis and the axis of the proximal femoral diaphysis as measured for AI (►**Fig. 2**).

### Femoral Trochanteric Angle

The transverse plane from the same MPR used for the AI and aLDFA was used to measure the FCT. To create the transcondylar axis in this plane, the grid lines of the imaging software were orientated so that they intersected the caudal aspect of both femoral condyles. A maximum intensity projection was created several centimetres thick to allow visualization of both the greater and lesser trochanters and a line was drawn intersecting both. If both could not be visualized on the same image of the MPR due to part of the pelvis obscuring the view, then further gridlines of the imaging software were used to identify the point of the lesser trochanter. The images were then scrolled through proximally until the greater trochanter was visible and a line drawn between the two points. The FCT was calculated as the angle between the transcondylar axis and the proximal line between the greater and lesser trochanters (►**Fig. 3**).

### Angle of Anteversion of the Femoral Neck

The AA was created from the same transverse plane MPR as the FCT. A line was drawn between the centre of the femoral head and the midpoint of the femoral neck representing the femoral neck axis. The AA was calculated as the angle between the femoral neck axis and the transcondylar axis (►**Fig. 4**).

### Distal Anteversion Angle

The DAA was created from the same transverse plane MPR as the FCT. A line was drawn from the lesser trochanter to the point of intersection of the transcondylar axis and the axis of

 

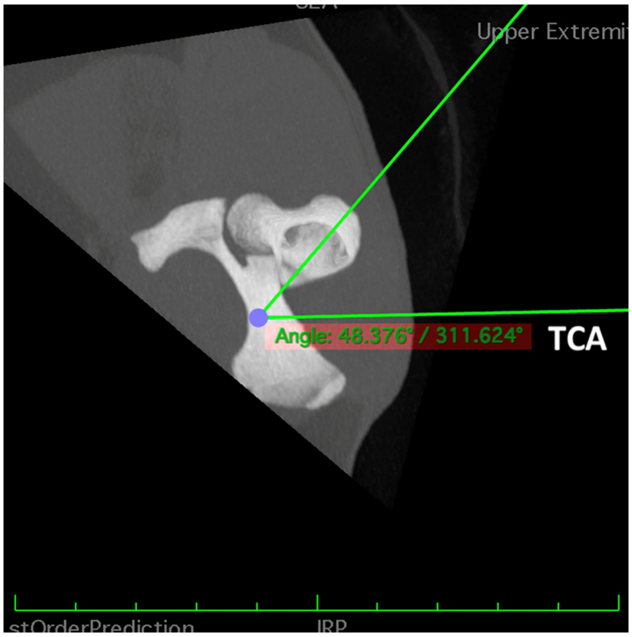


**Fig. 3** Transverse plane computed tomography scan demonstrating measurement of the femoral trochanteric angle (FCT). To create the transcondylar axis (TCA) in this plane, the grid lines of the imaging software were orientated so that they intersected the caudal aspect of both femoral condyles. A maximum intensity projection was created several centimetres thick to allow visualization of both the greater and lesser trochanters and a line was drawn intersecting both. The FCT was calculated as the angle between the transcondylar axis and the proximal line between the greater and lesser trochanters.

the femoral neck as created when calculating the AA. The DAA was the angle between this line and the transcondylar axis (►**Fig. 5**).

### Proximal Anteversion Angle

The PAA was created by subtracting the DAA from the AA.

### Overall Tibial Valgus

The MPR was manipulated so that the frontal plane intersected the caudal points of the tibial condyles proximally and

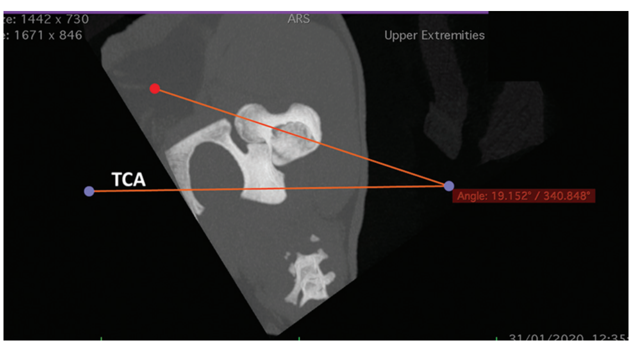


**Fig. 4** Transverse plane computed tomography scan demonstrating measurement of the angle of anteversion of the femoral neck (AA). The AA was created from the same transverse plane multiplanar reconstruction as the femoral trochanteric angle. A line was drawn between the centre of the femoral head and the midpoint of the femoral neck representing the femoral neck axis. The AA was calculated as the angle between the femoral neck axis and the transcondylar axis (TCA).

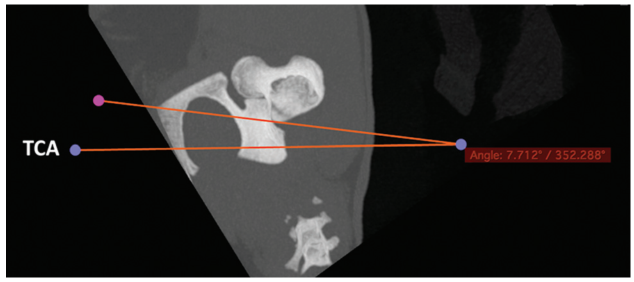


**Fig. 5** Transverse plane computed tomography scan demonstrating measurement of the distal anteversion angle (DAA). The DAA was created from the same transverse plane multiplanar reconstruction as the femoral trochanteric angle and AA. A line was drawn from the lesser trochanter to the point of intersection of the transcondylar axis (TCA) and the axis of the femoral neck as created when calculating the AA. The DAA was the angle between this line and the TCA.

the caudal aspect of the tibia distally. The TV was calculated on the frontal plane. A line was drawn to identify the proximal tibial joint line and the grid lines of the imaging software orientated to match this. The distal tibial joint line was then drawn, and TV was calculated as the angle between these (►**Fig. 6**).

### Tibial Torsion

Tibial torsion was calculated on the same MPR created for TV. The transverse plane was used to measure TT. A line was drawn between the caudal aspect of the medial and lateral tibial condyles proximally and the grid lines of the imaging software orientated to match this. A second line was drawn along the cranial surface of the distal tibia. The TT was measured as the angle between these (►**Fig. 7**).

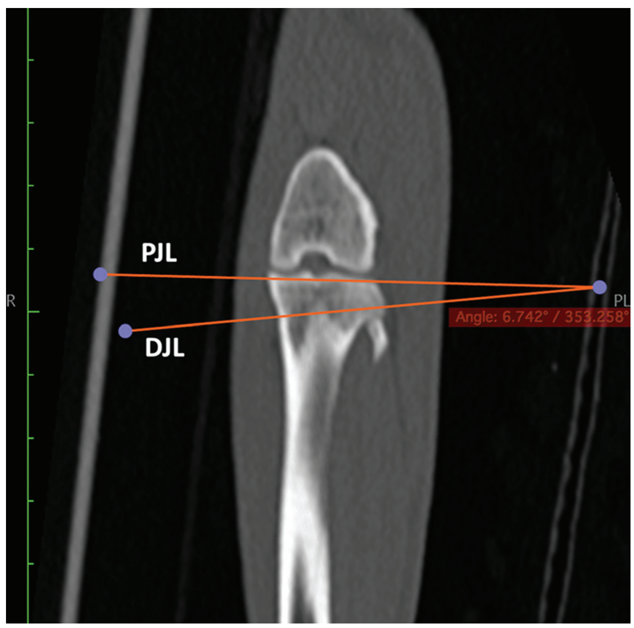


**Fig. 6** Frontal plane computed tomography scan demonstrating measurement of the overall tibial valgus (TV). A line was drawn to identify the proximal tibial joint line (PJL) and the grid lines of the imaging software orientated to match this. The distal tibial joint line (DJL) was then drawn, and TV was calculated as the angle between these.



 

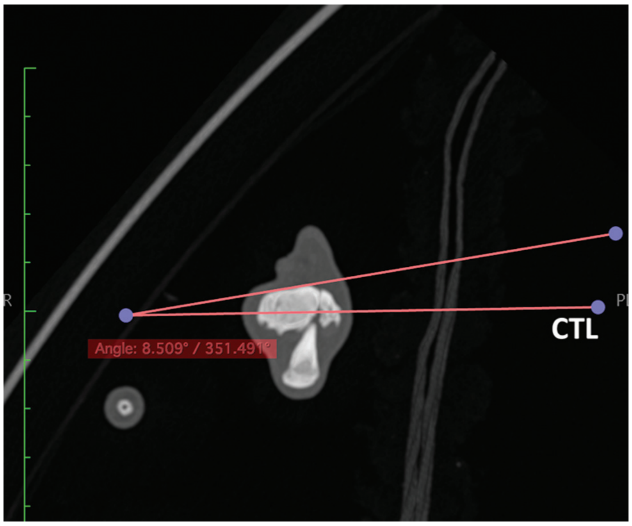


**Fig. 7** Transverse plane computed tomography scan demonstrating measurement of the tibial torsion (TT). A line was drawn between the caudal aspect of the medial and lateral tibial condyles proximally (CTL) and the grid lines of the imaging software orientated to match this. A second line was drawn along the cranial surface of the distal tibia. TT was the angle between these.

### Tibial Tuberosity Displacement

Tibial tuberosity displacement was calculated on the same MPR created for TV. The transverse plane was used to measure TTD with a maximum intensity projection that allowed both tibial condyles and the insertion of the patellar ligament on the tibial tuberosity to be visualized simultaneously. The width of the tibia was measured. A line was drawn between the caudal aspect of the medial and lateral tibial condyles proximally. A second line was drawn perpendicular to this that transected the middle of the width of the tibia. A final line was drawn from the midpoint of the insertion of the patellar ligament on the tibial tuberosity to the point of intersection between the previous two lines. The angle between this line and the line intersecting the middle of the tibia was the TTD. This was negative if the tibial tuberosity was medial to the line intersecting the middle of the tibia (►**Fig. 8**).

### Trochlear Depth/Patellar Thickness Ratio

The ratio of trochlear depth (T) to patellar thickness (P) was calculated. The MPR was manipulated so that the gridlines on the frontal plane and sagittal plane intersected the centre of the head of the femur proximally and the articulation between the femur and tibia distally. Using transverse plane, a line was drawn across the cranial most parts of both trochlear ridges. A parallel line at the base of the trochlear groove was also drawn. The distance between the two lines was the trochlear depth (►**Fig. 9**). The trochlear depth was measured every 2 millimetres along the length of the trochlear groove and the largest measurement recorded. The long axis of the MPR was rotated so it matched the long axis of the patella. Two parallel lines were drawn at the most cranial and caudal parts of the patella and measurements performed every 2 millimetres (►**Fig. 10**). The largest measurement was recorded as the patellar thickness. The ratio between trochlear depth and patellar thickness (T:P) was calculated with a value of 1 describing a patella that sat completely within the trochlear groove and 0 indicated absence of the trochlear groove.

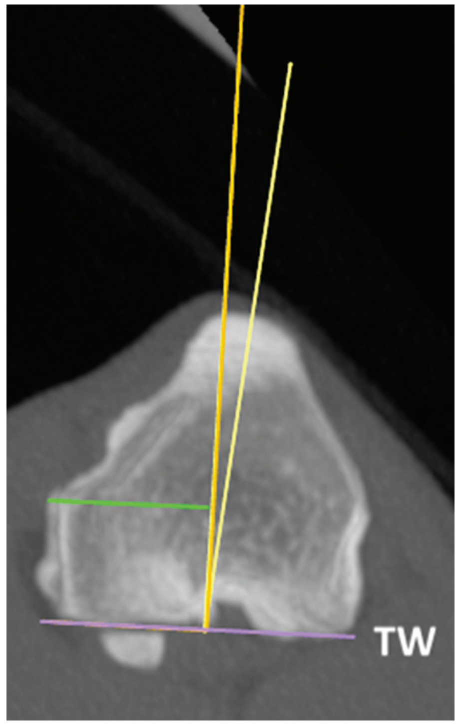


**Fig. 8** Transverse plane computed tomography scan demonstrating measurement of the tibial tuberosity displacement (TTD). The width of the tibia was measured (TW). A line was drawn between the caudal aspect of the medial and lateral tibial condyles proximally. A second line was drawn perpendicular to this that transected the middle of the width of the tibia. A final line was drawn from the midpoint of the insertion of the patellar ligament on the tibial tuberosity to the point of intersection between the previous two lines. The angle between this line and the line intersecting the middle of the tibia was the TTD.

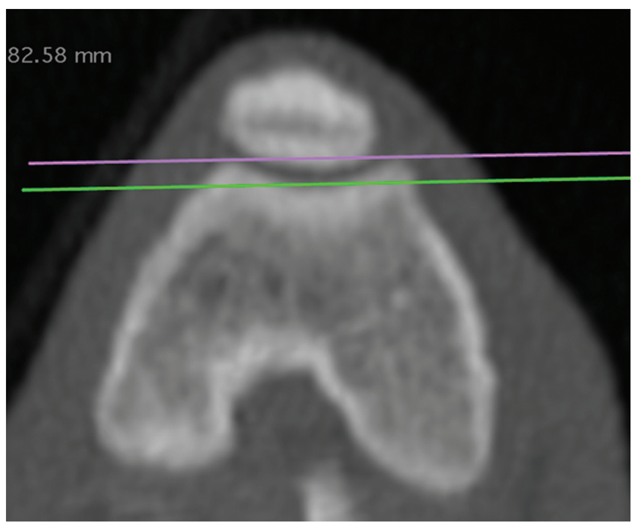


**Fig. 9** Transverse plane computed tomography scan demonstrating measurement of trochlear depth (T). A line was drawn across the cranial most part of the trochlear ridges. A second line was drawn parallel to this at the base of the trochlear groove at its deepest point. The trochlear depth was the difference between these.

 

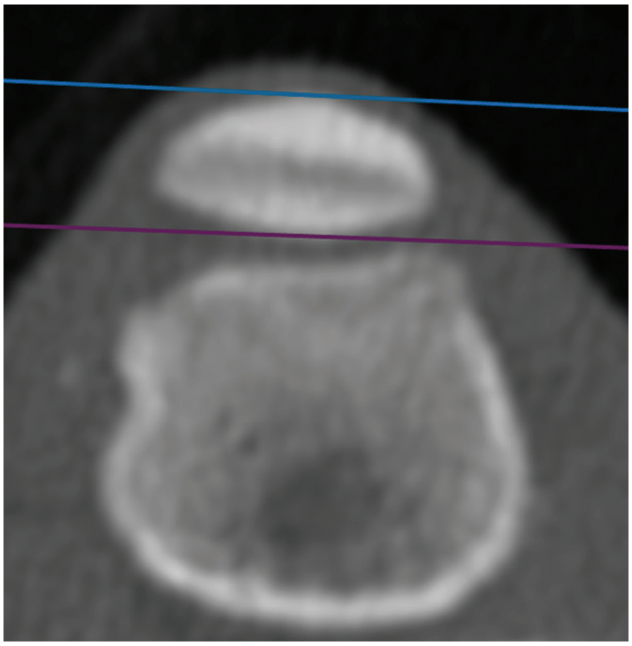

**Fig. 10** Transverse plane computed tomography scan demonstrating measurement of patellar thickness (P). A line was drawn across the cranial most part of the patella. A second line was drawn parallel to this at the most caudal part of the patella at its widest point. The patellar thickness was the difference between these.

### Statistical Analysis

Measurements for the three observers were recorded and entered into a spreadsheet (Microsoft Excel, Washington, United States). For both the luxation and control groups, individual limbs were included for analysis. If a cat within the luxation group had unilateral patellar luxation, then the normal limb was excluded from analysis. Statistical analyses were performed using SPSS (IBM Statistics version 19, New York, United States). Data were tested for normality using the Shapiro–Wilk test. Continuous data were analysed using a Student's *t*-test when normally distributed and a Mann–Whitney U test when not normally distributed. The means of the ten measurements from the three observers were compared between cats with low-grade medial patellar luxation (grade 1 or 2) and cats without medial patellar luxation. The means were also compared between cats with high-grade medial patellar luxation (grade 3 or 4) and cats without medial patellar luxation. Comparisons were also made between the measurements of the three observers by calculating the intraclass correlation coefficient (ICC) for the ten measurements for both the luxation and control groups. This correlation was considered high if ICC more than or equal to 0.75, good if ICC more than or equal to 0.60 but less than 0.74, fair if ICC more than or equal to 0.4 but less than 0.59 and poor if ICC less than 0.40.[28]

## Results

Sixteen cats were recruited into the study: eight control cats (16 limbs) and eight cats with medial patellar luxation (15 limbs). Seven of the eight affected cats had bilateral medial luxation with one cat being affected only on the left hindlimb. The 15 limbs with medial patellar luxation were graded as follows: grade 1 ($n=1$), grade 2 ($n=9$), grade 3 ($n=3$), grade 4 ($n=2$). Breeds in the luxation group were domestic short hair ($n=5$), domestic long hair ($n=2$) and Maine Coon ($n=1$). Breeds in the control group were domestic short hair ($n=6$), Ragdoll ($n=1$) and British Shorthair ($n=1$).

Control cats had mean age of 2.97 years (standard deviation [SD]: 1.99), cats with low-grade medial patellar luxation had a mean age of 2.22 years (SD: 1.61) and cats with high-grade medial patellar luxation had a mean age of 2.56 years (SD: 1.78). Control cats had mean weight of 4.39kg (SD: 0.73), cats with low-grade medial patellar luxation had a mean weight of 4.93kg (SD: 1.34) and cats with high-grade medial patellar luxation had a mean weight of 3.08kg (SD: 1.41). There were six males (five neutered, one entire) and two females (one neutered, one entire) in the control group, four males (three neutered, one entire) and one female (neutered) in the low-grade luxation group and one male (neutered) and two females (both neutered) in the high-grade luxation group.

The measurements of affected and control limbs are summarized in ►**Tables 1** and **2**. All measurements were normally distributed other than aLDFA, TV and TT for the luxation groups. The AI was significantly higher in the low-grade luxation group with a mean of 128.07 degrees compared to 125.85 degrees in the control group. The aLDFA was found to be significantly less in cats with high-grade medial patellar luxation with a mean of 88.39 degrees compared to 91.21 degrees in the control group. The low-grade luxation group had significantly less overall anteversion than the control group. Mean AA was 21.61 degrees in the low-grade luxation group compared to 24.23 degrees in the control group. Both luxation groups had significantly less proximal anteversion than the control group. Mean PAA was 11.55, 12.02 and 13.79 degrees in the high- and low-grade luxation groups and the control group respectively. Both luxation groups also had a significantly lesser degree of TT, with a mean of −1.15 and 7.64 degrees of torsion in the high- and low-grade groups respectively, compared to 9.41 degrees in the control group. There was more medialization of the tibial tuberosity in both luxation groups with a mean TTD of –3.76 and more than or equal to 3.84 degrees in the high- and low-grade luxation groups respectively compared to more than or equal to 1.80 degrees in the control group. The trochlear depth to patellar thickness ratio was significantly less in both the high- and low-grade luxation groups when compared to the control group; mean T:P ratio 0.11, 0.28 and 0.32 respectively. The aLDFA, FCT, DAA and TV were not significantly different between the control group and low-grade group. The AI, FCT, AA, DAA and TV were not significantly different between the control group and high-grade group.

A high correlation was shown with the inter-observer ICC in 33.33% of the measurements, good correlation in 26.67%, fair correlation in 11.67% and poor correlation in 28.33% (►**Table 3**). When comparing observer 1 (board-certified specialist) and observer 2 (surgical resident), inter-observer ICC indicated a high correlation in 45%, good correlation in 15%, fair correlation in 25% and poor correlation in 15%. When comparing observer 1 (board-certified specialist) and

 

**Table 1** Comparing combined measurements (degrees) from all three observers between control and low-grade luxation groups (grade 1 and 2)

| Measurement | Control group (Mean ± SD) | Low-grade luxation group (Mean ± SD) | *p*-Value |
|---|---|---|---|
| AI | 125.85 ± 2.83 | 128.07 ± 2.79 | 0.002 |
| aLDFA | 91.21 ± 1.69 | 90.73 ± 1.93 | 0.490 |
| FCT | 46.30 ± 4.69 | 45.37 ± 3.96 | 0.381 |
| AA | 24.23 ± 3.83 | 21.61 ± 3.34 | 0.004 |
| DAA | 10.44 ± 2.60 | 9.59 ± 2.08 | 0.148 |
| PAA | 13.79 ± 2.38 | 12.02 ± 2.37 | 0.003 |
| TV | 8.62 ± 2.98 | 8.82 ± 1.55 | 0.645 |
| TT | 9.41 ± 2.27 | 7.64 ± 2.66 | 0.017 |
| TTD | −1.80 ± 2.33 | −3.84 ± 1.86 | 0.001 |
| T:P ratio | 0.32 ± 0.05 | 0.28 ± 0.09 | 0.011 |

Abbreviations: AA, angle of anteversion of femoral neck; AI, angle of inclination; aLDFA, anatomic lateral distal femoral angle; DAA, distal anteversion angle; FCT, femoral trochanteric angle; PAA, proximal anteversion angle; SD, standard deviation; T:P ratio, trochlear depth/patella thickness ratio; TT, tibial torsion; TTD, tibial tuberosity displacement; TV, tibial valgus. Values of $p < 0.05$ were considered significant.

observer 3 (board-certified specialist), inter-observer ICC indicated a high correlation in 30%, good correlation in 25%, fair correlation in 5% and poor correlation in 40%. When comparing observer 2 (surgical resident) and observer 3 (board-certified specialist), inter-observer ICC indicated a high correlation in 25%, good correlation in 40%, fair correlation in 5% and poor correlation in 30%.

## Discussion

In this study comparing the femoral and tibial conformation measured on CT in a population of normal cats and a population of cats with medial patellar luxation, it was found that overall and proximal femoral torsion (AA/PAA), TT and the ratio of trochlear depth to patellar thickness were significantly decreased in cats with low-grade medial patellar luxation, AI was greater and the tibial tuberosity was more medialized in cats with low-grade medial patellar luxation when compared to normal cats, leading us to reject our null hypothesis.

Historically the degree of medial patellar luxation is graded according to the Singleton criteria.[11,26] Whilst this is appropriate for dogs, cats have a relatively higher physiological laxity of the patella and grading systems developed for dogs should be used with caution.[29] An alternative grading scale has been suggested for use in cats.[29] All control

**Table 2** Comparing combined measurements (degrees) from all three observers between control and high-grade luxation groups (grade 3 and 4)

| Measurement | Control group (Mean ± SD) | High-grade luxation group (Mean ± SD) | *p*-Value |
|---|---|---|---|
| AI | 125.85 ± 2.83 | 125.85 ± 4.42 | 0.997 |
| aLDFA | 91.21 ± 1.69 | 88.39 ± 2.83 | 0.001 |
| FCT | 46.30 ± 4.69 | 44.83 ± 4.77 | 0.308 |
| AA | 24.23 ± 3.83 | 23.25 ± 7.37 | 0.526 |
| DAA | 10.44 ± 2.60 | 11.71 ± 4.14 | 0.181 |
| PAA | 13.79 ± 2.38 | 11.55 ± 4.28 | 0.017 |
| TV | 8.62 ± 2.98 | 10.15 ± 4.91 | 0.458 |
| TT | 9.41 ± 2.27 | −1.15 ± 8.37 | 0.000 |
| TTD | −1.80 ± 2.33 | −3.76 ± 2.25 | 0.006 |
| T:P ratio | 0.32 ± 0.05 | 0.11 ± 0.10 | 0.000 |

Abbreviations: AA, angle of anteversion of femoral neck; AI, angle of inclination; aLDFA, anatomic lateral distal femoral angle; DAA, distal anteversion angle; FCT, femoral trochanteric angle; PAA, proximal anteversion angle; SD, standard deviation; T:P ratio, trochlear depth/patella thickness ratio; TT, tibial torsion; TTD, tibial tuberosity displacement; TV, tibial valgus. Values of $p < 0.05$ were considered significant.

**Table 3** Inter-observer ICC between the three observers for the two groups

| Measurement | Observer 1 vs. observer 2 | | Observer 1 vs. observer 3 | | Observer 2 vs. observer 3 | |
|---|---|---|---|---|---|---|
| | Control group | Luxation group | Control group | Luxation group | Control group | Luxation group |
| AI | 0.430 | 0.860 | 0.132 | 0.810 | 0.140 | 0.748 |
| aLDFA | 0.441 | 0.802 | 0.676 | −0.682 | 0.603 | −0.796 |
| FCT | 0.823 | 0.089 | 0.771 | 0.503 | 0.911 | 0.656 |
| AA | 0.515 | 0.801 | 0.308 | 0.939 | 0.654 | 0.641 |
| DAA | 0.647 | 0.617 | 0.647 | 0.737 | 0.606 | 0.367 |
| PAA | 0.392 | 0.905 | 0.103 | 0.859 | 0.726 | 0.750 |
| TV | 0.425 | 0.862 | 0.177 | 0.747 | 0.504 | 0.787 |
| TT | 0.677 | 0.987 | 0.649 | 0.983 | 0.617 | 0.964 |
| TTD | −0.106 | 0.782 | 0.584 | −0.070 | 0.390 | −0.289 |
| T:P ratio | 0.557 | 0.907 | 0.152 | 0.956 | −0.637 | 0.917 |

Abbreviations: AA, angle of anteversion of femoral neck; AI, angle of inclination; aLDFA, anatomic lateral distal femoral angle; DAA, distal anteversion angle; FCT, femoral trochanteric angle; ICC, intraclass correlation coefficient; PAA, proximal anteversion angle; SD, standard deviation; T:P ratio, trochlear depth/patella thickness ratio; TT, tibial torsion; TTD, tibial tuberosity displacement; TV, tibial valgus. Correlations were considered high (ICC $\geq$ 0.75), good ($\geq$ 0.60 ICC $<$ 0.74), fair ($\geq$ 0.4 ICC $<$ 0.59), or poor (ICC $<$ 0.40).

cases were assessed to ensure that they did not have patellar luxation to prevent a cat with patellar luxation entering the control group and skewing the data.

Computed tomography was used in this study as it has been shown previously to provide a good way of assessing femoral and tibial alignment and is less reliant on patient positioning when compared to radiographs.[7,9,10,30] Barnes and colleagues (2014) demonstrated good intra- and inter-observer repeatability in dogs when assessing femoral and tibial alignment using CT.[21] The findings of our study vary somewhat from their reported ICC more than 0.8 for their five measurements. Only 33.33% of our measurements had a high correlation between observers with another 26.67% having a good correlation, although only three of our measurements are the same as those compared in their study. A poor correlation between observers was found in 28.33% of our measurements. Six of the inter-observer ICC were negative likely indicating that the variability within the group was greater than across the groups suggesting caution when interpreting the correlations for these six measurements.

Whilst most of the measurements were relatively easily repeatable, measuring the FCT and DAA in this study did highlight some issues. When performing MPR with a thicker maximum intensity projection, the greater and lesser trochanters were not always visible in the same image due to regions of the pelvis being superimposed over the lesser trochanter. Although no protocol was present for the positioning of cats when acquiring CT data, it may be prudent to ensure hips are not fully extended to avoid regions of the pelvis overlying and obscuring femoral landmarks with a thicker maximum intensity projection, which was the case in a few of the cats in this study. When obtaining measurements, this was overcome by using the outer set of gridlines of the DICOM viewer orientated over the lesser trochanter when viewed on the transverse plane. This allowed accurate identification of the location of the lesser trochanter relative to the rest of the femur on the transverse plane even when it was not visible on the slice being viewed. This permitted a thinner maximum intensity projection to be used eliminating the regions of the pelvis that were superimposed over the lesser trochanter on a thicker maximum intensity projection. A previous study assessing pelvic limb alignment in English Bulldogs had a protocol to position the dogs in dorsal recumbency with hips, stifles and hocks flexed at 90 degrees which likely prevents this issue.[10] This was not performed in this study for as we did not anticipate it to be an issue with the three-dimensional reconstructions; however, this positioning would be recommended in the future when assessing these angles. There was also some degree of subjectivity noted when determining the midpoint of the greater and lesser trochanter and likewise for the distal tibial joint line and midpoint of the insertion of the patellar ligament on the tibial tuberosity, which may explain the variation noted. It is possible that determining these measurements in cats is less repeatable than dogs due to the difference in anatomy and less easily identified landmarks. Alternatively, it could be due to a variation in observer technique such as errors in the orientation of the reconstruction plane, inaccurate identification of landmarks or inaccurate measurements. Further investigation is required with larger case numbers to determine if our findings are true.

Tibial torsion was identified as significantly less in both the luxation groups with these cats having medialization of the tibial tuberosity, a finding previously reported in dogs.[9,31] The difference between the low-grade luxation group and the control group was only a few degrees and unlikely to be clinically significant; however, this difference was much larger in the high-grade luxation group. This was most apparent in one of the grade 4 cats that had a negative torsion value with marked medialization of the tibial tuberosity. Tibial tuberosity displacement was significantly greater between the two luxation groups and the control group in this study. A previous study hypothesized that torsional tibial deformities were presumed to be compensatory as a result of altered weight bearing with uneven physeal pressures during growth.[32–34] Lateral transposition of the tibial tuberosity is commonly used in dogs with medial patellar luxation to correct medial displacement[18,24,35,36] however, in our experience some cats do not need transposition of the tibia. Based on our findings, it is likely that tibial tuberosity transposition may only be necessary in grade 3 and grade 4 cats. A corrective osteotomy and de-rotation of the tibia are not required except in only the most severely affected cases.[31] Clinical decision making should be made on a case-by-case basis.

Proximal anteversion was significantly less in both the high- and low-grade luxation group suggesting the femoral head and neck in these cats contributes to the overall reduction in anteversion. A similar finding has been reported previously in English Staffordshire Bull Terriers with medial patellar luxation, although this study found that the anteversion was contributed mainly by femoral diaphyseal torsion (DAA) rather than PAA.[7] Torsional corrective osteotomies are performed in dogs to correct decreased AA and the degree of correction is often calculated from the normal hindlimb if the dog is unilaterally affected, or anatomical specimens of a similar sized dog if bilateral deformities are present.[7,17,32] One study reported a target value of approximately 27 degrees when performing a femoral osteotomy to correct femoral torsion.[18] Other authors consider correction of femoral torsion is seldom required in cases of medial patellar luxation.[37] Although significant the mean values for PAA between the groups were very similar, with the difference between control group and clinically affected cats less than three degrees, suggesting these differences may not be clinically significant and femoral torsional corrective osteotomies are not required in the majority of cases.

There was a significantly lower aLDFA in the high-grade luxation group which suggests that cats with medial patellar luxation do not suffer from distal femoral varus as previously described in dogs.[9,10] Severe distal femoral varus in dogs is usually corrected with a closing wedge ostectomy.[7,19,20] Another study in dogs revealed no increase in postoperative complication in dogs with medial patellar luxation and distal femoral varus that did not have surgical correction of the deformity, concluding that further work is required to determine which cases require distal femoral osteotomies.[38] In dogs with distal femoral varus, ostectomies are reserved for cases with marked deformities with an aLDFA greater than 102 degrees or femoral varus angle greater than 12 degrees to help realign the quadriceps mechanism.[20] Based on our data corrective femoral osteotomy or ostectomy for valgus or varus deformities are not required in cats with medial patellar luxation as, although the difference between our groups was significant, they may not be clinically significant as the mean aLDFA varied by less than 3 degrees and values for both groups were close to 90 degrees. The aLDFA has been shown to vary with breeds of dog and the lack of breed standardization between groups in our study may account for the difference seen.[7,9,10] The AI was not significantly different between the cats with high-grade luxation and the control group which differs from a previous report in dogs where coxa valga was associated with medial patellar luxation.[39] Outliers in the high-grade luxation group may have resulted in the mean of the group being lower and subsequently reducing any significant difference relative to the control group. Cats with low-grade luxation had significantly greater AI, although again this was less than 3 degrees greater than control cats so unlikely to be clinically significant. The ICC was also particularly low for these measurements suggesting caution when interpreting the results.

A partial parasagittal patellectomy is a technique that has more recently been described[4–6] and was only performed in a few cats in this study. Computed tomography has shown that it improves patellar recession and contact with the trochlear sulcus.[6] There was a significant difference in the trochlear depth to patellar thickness ratio between both the high- and low-grade luxation groups and the control group with cats with patellar luxation having a much shallower trochlear groove relative to the patellar thickness. The difference in the trochlear depth to patellar thickness was much greater when comparing the high-grade luxation group suggesting a femoral trochleoplasty is required in these cats, although the authors perform trochleoplasty in most cats with medial patellar luxation. Presence of patella alta or baja was not assessed between the two populations during this study as it has been in others.[40]

Femoral and tibial joint angles have previously been reported in the normal cat but these were measured using radiography.[22,25] The mean AI in our control group was $125.85 \pm 2.83$ which is higher than the $121.9 \pm 4.1$ reported previously.[25] This could be due to the variation in breeds included in our study compared to just domestic shorthair being included in the previous study. Alternatively, it could be due to the different measurements obtained with radiography compared to CT. The mean aLDFA in our control group was $91.21 \pm 1.69$ which was comparable to $91.9 \pm 2.1$ previously reported in one study,[25] although lower than $93.8 \pm 2.5$ reported in another.[22] Although both previous studies measured proximal and distal tibial joint angles separately, they did not calculate overall TV.[22,25] Femoral trochanteric angle, AA, DAA, PAA, TT and TTD were also not reported in either previous study.[22,25] This is likely due to the difficulty of measuring these values on conventional two-dimensional radiographs compared to a three-dimensional reconstruction obtained with CT.

Limitations of this study include its small case numbers. No similar studies exist in cats so sample size was calculated based on a previous similar study in dogs.[7] The low case numbers in this study may result in a type II error; thus, results may need to be interpreted with caution. It is possible that other measurements may become significant if greater case numbers were present. Grading of patellar luxation can have a degree of subjectivity and individuals may not always fit clearly into a single category. Previous studies have reported that Devon Rex and Abyssinian breeds are more prone to medial patellar luxation[3,41,42]; neither of which are included in this study. Although often referred to as commonly affected breeds, these were, however, from single small cases series and this breed predisposition may not be relevant to the current feline population.

## Conclusion

The findings of our study suggest that cats with both high- and low-grades of medial patellar luxation have medialization of the tibial tuberosity and a shallow trochlear groove but a tibial tuberosity transposition is likely only necessary in grade 3 and 4 cats. Cats with medial patellar luxation also have decreased proximal anteversion of the femur, and decreased aLDFA relative to a normal cat population, although the clinical significance of these may vary and correctional osteotomies are unlikely to be required in cats. The results of this study should be interpreted with caution as a high or good level of inter-observer ICC was only demonstrated in less than two-thirds of cases. Further investigation of femoral and tibial confirmation in cats with medial patellar luxation is required with larger sample sizes.

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Conflict of Interest
None declared.

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