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The Quadriceps Angle: Reliability and Accuracy in a Fox (*Vulpes vulpes*) Pelvic Limb Model

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Objectives: To evaluate the effect of measurement technique and limb positioning on quadriceps (Q) angle measurement, intra- and interobserver reliability, potential sources of error, and the effect of Q angle variation.
Study Design: Cadaveric radiographic study and computer modeling.
Animals: Pelvic limbs from red foxes (*Vulpes vulpes*).
Methods: Q angles were measured on hip dysplasia (HD) and whole limb (WL) view radiographs of each limb between the acetabular rim, mid-point (Q1: patellar center, Q2: femoral trochlea), and tibial tuberosity. Errors of 0.5–2.0 mm at measurement landmarks alone and in combination were modeled to identify the effect on Q angle. The effect of measured Q angles on the medial force exerted on the patella (F_{MEDIAL}) was calculated.
Results: The HD position yielded significantly ($P < .001$) more medial Q angles than the WL position. No significant difference was observed between Q1 and Q2, but Bland–Altman plots indicated they were not equivalent. Intra- and interobserver agreement was substantial. Q2 errors were inherently greater than Q1: the mid-point and tibial tuberosity are the most important sources of Q angle variability. Increasing Q angles significantly increased the exerted F_{MEDIAL} ($P <$ .0001, gradient 1.7%).
Conclusions: Measurements are reliable, but Q2 is more prone to error than Q1, and the 2 measurement techniques are not interchangeable. Positional errors must be kept below 1.3 mm (Q1) or 0.8 mm (Q2).

Medial patellar luxation is a common, disabling orthopedic condition which particularly affects small breed dogs, although the incidence in larger dogs appears to be increasing.[1–3] Diagnosis is generally made by clinical examination and graded according to clinical severity.[4,5] The cause of luxation is a multifactorial alignment disorder of the quadriceps mechanism with an unclear pathogenesis.[1,3,5] Despite surgical stabilization of the patella, long-term problems such as recurrence of luxation or progressive degenerative joint disease are not uncommon.[6,7] Because validated objective criteria for pre- and post-operative assessments of pelvic limb alignment are lacking, surgical correction tends to be rather subjective in its approach.[8]

A candidate criterion for objectively assessing quadriceps alignment is the quadriceps angle (Q angle). Current Q angle data for normal dogs are derived from an MRI study[9] of 37 limbs, with a mean ± SD medial Q angle of 10.5 ± 5.6°. The precise weights and ages of these normal dogs were not reported, although the study included 17 different breed groups with ages between 8 months and 13 years. The wide range of this reported mean Q angle may be caused by the variation in age and size of the sample population.

The Q angle is measured clinically in people as the angle between the quadriceps resultant (defined as a line connecting the anterior superior iliac spine and the center of the patella[10]) and a line oriented along the patellar tendon.[11] The anterior superior iliac spine is a palpable landmark in people and is used as a proxy for the origin of the rectus femoris muscle.[12] Neither of these points is palpable in dogs. The Q angle has been assessed with MRI[9] in normal dogs and radiographically[8,13] and with CT[8] in dogs affected with medial patellar luxation. For radiography, a ventrodorsal view suitable for hip dysplasia (HD) assessment is used.[8,13]

Several problems with Q angle measurement in people have been recognized.[12] Of these, alteration or reduction of the measured Q angle because of subluxation or luxation

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of the patella during measurement and the introduction of error because of distal limb rotation are pertinent to veterinary investigations.

Internal rotation of the distal limbs may be used to correctly align the femora for imaging, but is also recognized as a means to provoke luxation during clinical examination.[1,5] Internal rotation is limited by the lateral collateral ligament at or near full extension, and extension of the stifle for imaging is therefore recommended.[9] Use of MRI or CT to identify the trochlear center at the level of the patella compensates for inaccuracies associated with subluxation and luxation.[9,12] Radiographically, compensation takes the form of using an alternative landmark (the intercondylar notch) as a proxy for the trochlea at the level of the patella.[8] We are unaware of published information regarding the validity of this substitution on radiographically measured Q angles.

The effect of different limb positioning techniques on Q angle measurement is unknown. We typically take ventrodorsal radiographs under sedation with manual positioning, and an internal torque is applied to the distal limb to center the stifle joints. For CT or MRI, or when radiation protection legislation prohibits manual restraint, alternative positioning methods must be used. One method by which the necessary internal rotation can be achieved is by the use of tapes and ties at the level of the distal femora, with the distal limbs unconstrained, other than to achieve extension of the stifle joints.[14]

The effect of error in landmark location on the measured Q angle has been assessed in people,[15] by modeling errors of 1–5 mm along mediolateral and proximodistal axes at the centers of the anterior superior iliac spine, patella, and tibial tuberosity. It was determined that the locations of the patella and tibial tuberosity had to be defined within 2 mm of their true position to keep measurement error $< \pm 5^{\circ}$. Similar errors may account for some of the variability between reported values for the Q angle in people. We are not aware of similar reports in dogs.

We selected a homogenous group of animals unaffected by medial patellar luxation and of corresponding size to the typical affected population, to minimize interindividual variation because of breed and size. The red fox (*Vulpes vulpes*) was chosen, because its limb morphology is very similar to that of the domestic dog[16,17] and cadavers were readily available.

We hypothesized that Q angles measured using either the patella or the intercondylar notch as the middle landmarks would not differ to a clinically significant degree, but that the use of 2 positioning methods with different degrees of distal limb constraint would yield clinically significant differences. We further hypothesized that use of a homogenous sample population would result in tighter reference intervals for normal Q angles than previously reported. Additionally, we wanted to investigate the potential influence of landmark location accuracy and the effect of varying Q angle on the forces applied to the patella, along with intra- and interobserver variation in Q angle measurements.

MATERIALS AND METHODS

Radiographic Study

Cadavers of 12 skeletally mature red foxes (6 male, 6 female) obtained from a commercial farm were studied. Cadavers were frozen immediately after transport and thawed to room temperature before imaging. Pelvic limbs that had gross or radiographic signs of damage to the appendicular skeleton were excluded from analysis. All patellae were assessed as stable on examination.

Digital radiographs were obtained using the standard ventrodorsal view used for HD scoring in our clinic, ensuring that the proximal tibia was included in the radiograph. The femora were required to be extended parallel, with the distal limbs internally rotated to ensure that the stifle joints were straight, as assessed by bisection of the fabellae and centering of the patella in the trochlea.[18] The pelvis was required to be symmetrically positioned and aligned with the femora.[14]

Subsequently whole limb (WL) digital radiographs were obtained using a caudocranial projection of each individual pelvic limb with the cadaver in ventral recumbency, and the radiographic beam vertical and centered over the stifle. The pelvic limb and stifle joint were extended, and gentle rotation of the distal limb used to position the stifle joint so that the fabellae were bisected and the patella centered in the trochlea on the radiograph.

Radiographic images that met the above criteria were digitally archived as DICOM files. Subsequently the DICOM files were anonymized and cropped using commercial software (Sante DICOM Editor, Santesoft, Athens, Greece) to produce uniformly orientated single images for each limb and limb position. Right limb images were mirrored so that all limbs were viewed in the same orientation. The edited files were randomized separately for 3 readings and readings were performed using software (Ant Renamer by Antoine Potten, www.antp.be/software/renamer; Synedra View Personal, Synedra Information Technologies GmbH, Innsbruck, Austria). The viewing software used permitted image magnification, manipulation of brightness and contrast, and the use of false color spectra.

The Q1 angle was measured as the angle between a line drawn from the cranial lip of the acetabulum to the center of the patella and a line from the center of the patella to the center of the tibial tuberosity for each image in each limb position (HD and WL). As a control for hip rotation between the 2 limb positions, an additional angle (the offset angle) was measured between the cranial lip of the acetabulum, the center of the patella, and the lateral cortex of the greater trochanter. Measurements were then repeated using the intercondylar notch in place of the center of the patella to obtain angle Q2 (Fig 1).

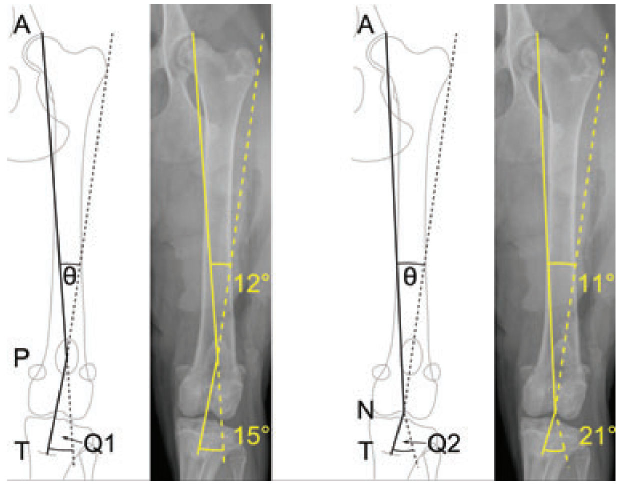

Figure 1 Q angle measurements (Q1 and Q2) and offset angles (θ) shown for the HD position. Paired outline and radiographic images are shown for Q1 (left) and Q2 (right). Landmarks for each measurement are A—cranial lip of the acetabulum, P—patellar center, N—intercondylar notch, and T—tibial tuberosity. The offset angle is used to control for acetabular shift between HD and WL positions for Q1 and Q2. Sample measurements are given on the radiographic images.

Readings were performed 3 times by 2 observers (JM, JVF), with different levels of clinical experience. Before starting the readings, landmark identification and use of the software were practiced to standardize techniques.

Measurements from limb position WL were corrected for hip rotation before statistical analysis, by addition of the difference between the offset angles for the 2 techniques. For example, Fig 1 shows a limb in position HD, with an offset angle θ_{HD}. In limb position WL, the pelvis is rotated clockwise relative to the femur, reducing the measured Q angle and the offset angle θ_{WL}. The difference between θ_{HD} and θ_{WL} represents the necessary addition to the Q angle to correct for rotation at the hip, allowing comparison between the different internal tibial rotations in the 2 positions.

Error Model

A simulation was created (Visual Basic for Applications in Excel; Microsoft, Redmond, WA). Coordinate data for the acetabular rim, patellar center, intercondylar notch, and tibial tuberosity were taken using the digital viewing software from all HD radiographs included in the analysis.

The 8 possible combinations of error present or error absent for the 3 measurement points were run against 4 sizes of potential error (0.5 mm, 1.0 mm, 1.5 mm, and 2.0 mm) for Q angle measurement techniques Q1 and Q2. The potential errors were modeled as radii centered on the original coordinate data and rotated from 10° to 360° in 10° steps about these points. New "erroneous" coordinates were calculated based on these radii and the Q angle determined from them. Maximum and minimum Q angles and the angles at which they occurred were recorded.

Effect of Varying Q Angle

The proximodistal axis of the femur in the frontal plane was defined as a line connecting the center of the diaphysis at one third and two thirds of the femoral length. The offset angle between this line and the line of the rectus femoris (defined as connecting the cranial lip of the acetabulum and the patellar center) was measured on all included HD images. Using coordinate data from the error model, the Q angle was calculated and the medial force resultant and its mediolateral component (F_{MEDIAL}) determined as detailed in Fig 2. This component force was expressed as a percentage of the quadriceps force and compared with the corresponding Q angle.

Statistical Analysis

Randomization and blinding were broken and data recovered regarding Q angle technique (Q1 or Q2), radiographic positioning (HD or WL), limb, observer, reading number (1–3), fox gender, and fox identification number.

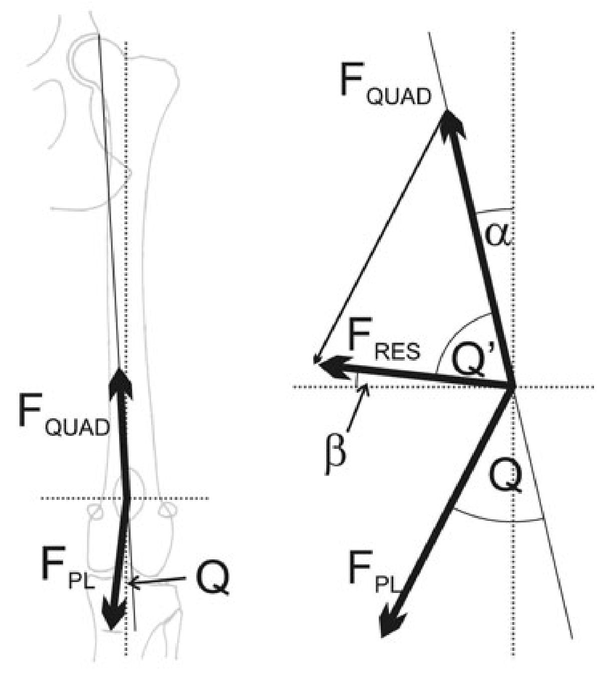

Figure 2 The effect of Q angle on patellar stability. Forces F_{QUAD} and F_{PL} are assumed to be equal in magnitude. The dotted lines represent the proximodistal and mediolateral axes. The resultant force F_{RES} has a magnitude of $2 \cdot F_{QUAD} \cdot \cos Q'$, where Q' is (180-Q)/2. If the quadriceps force is directed at angle α to the proximodistal axis, then F_{RES} will act at angle β to the mediolateral axis, where β is (90-Q'-α). The mediolateral component of F_{RES} (F_{MEDIAL}) may then be derived as $F_{RES} \cdot \cos \beta$.

Veterinary Surgery 41 (2012) 422–429

Statistical analysis was performed using software (SAS 9.1; SAS Institute, Cary, NC). Data were confirmed as normally distributed using quantile–quantile plots, residual plots and the Shapiro–Wilk test, and variances compared visually using box-plots. Data were reported as mean (SD) or mean (95% confidence intervals [95%CI]) where appropriate.

For intra- and interobserver comparisons, case 2 absolute agreement intraclass correlation coefficients (ICCs $_{(2,k)}$) were calculated for $k = 3$ readings or $k = 2$ observers according to Shrout and Fleiss.[19] Values were interpreted according to Shrout.[20] Within-subject standard deviations and coefficients of repeatability, rather than coefficients of variation, were calculated because the White test classed the standard deviations of the repeated measures as homoscedastic against the means of the repeated measures.[21]

Mean values for each limb for each technique and position were compared using a mixed model ANOVA with limb, gender, measurement technique, limb position, and the interaction of measurement technique with limb position as fixed effects and fox identity as a random effect, with adjustment for unequal variances between the 2 measurement techniques. The effects of limb position and measurement technique were further compared using Bland–Altman difference plots and limits of agreement.[22]

Means for the potential error ranges were calculated from the minimum and maximum Q angles achieved for each combination of error location and error radius in each limb.

The effect of varying Q angle on medially directed force was assessed by linear regression.

RESULTS

Of the 24 limbs radiographed, 21 pelvic limbs from 11 foxes were used for analysis because of exclusion of 2 left limbs (one male, one female) and one right limb (male) because the coxofemoral joints were luxated during radiography. Mean body weight was 8.2 kg (SD 1.7 kg) for the whole group, 9.1 kg (SD 1.9 kg) for the males, and 7.3 kg (SD 1.0 kg) for the females. There was no significant difference in body weight between genders ($P = .06$).

Radiographic Study

Larger Q angles were found for the HD position as compared to the WL position ($P < .001$). Mean pooled medially directed Q angles were 15.5° (SD 3.6°) for HD Q1, 16.7° (SD 7.5°) for HD Q2, 7.8° (SD 4.3°) for WL Q1, and 6.4° (SD 5.6°) for WL Q2.

No statistically significant effect was observed for limb ($P = .14$), gender ($P = .41$), technique (Q1 versus Q2; $P = .91$), or the interaction of positioning with technique ($P = .20$).

Bland–Altman difference plots (Fig 3) to compare HD with WL for Q1 and Q2, and Q1 with Q2 for HD and WL, confirmed the bias between HD and WL indicated by ANOVA. The limits of agreement were consistently wide at −8–11° (for WL Q1 with WL Q2), −3–19° (for Q1 HD with Q1 WL), and −6–26° (for Q2 HD with Q2 WL). The plot comparing Q1 with Q2 for HD showed non-uniform differences, necessitating a regression approach[23]: the limits of agreement increased from 14° to 16° with increasing mean Q angle.

Although the differences between the mean Q angles for left and right limbs were not statistically significant (0.22°, 0.35°, 4.1°, and 1.2° for HD Q1, HD Q2, WL Q1, and WL Q2, respectively), absolute inter-limb differences were larger at 3.1° (SD 2.6°) and 2.6° (SD 4.1°) for HD Q1 and Q2, respectively, and 5.6° (SD 3.2°) and 3.8° (SD 3.8°) for WL Q1 and Q2, respectively. The mean applied correction for hip rotation between positions HD and WL for Q1 and Q2 was 0.6° (SD 1.3°).

Error Simulation

Potential error ranges varied with error radius and with error location. Maximum error ranges for Q1 and Q2 produced by the simulation using radii from 0.5 mm up to 2 mm at all 3 locations are shown in Fig 4. The greatest influences on error magnitude were the tibial tuberosity and mid-point (patellar or intercondylar notch) with both measurement techniques: magnitudes were always greater for the Q2 technique except for the isolated acetabular lip situation.

The maximum and minimum Q angles were generally achieved along axes approximately perpendicular to the line of the femur. For the acetabular lip and tibial tuberosity, minima occurred with lateral displacement, and for the mid-point, with medial displacement. Maxima occurred in the opposite direction. The sole exception was for the acetabular lip point in the Q2 technique when combined with the intercondylar notch, when the maximum occurred with displacement along the line of the femur and away from the stifle.

Effect of Varying Q Angle

The mean offset angle between the proximodistal axis of the femur and the line of the rectus femoris muscle was 4.6° (SD 0.6°). Linear regression was performed with an intercept (Fig 5): a strong linear relationship was observed between the calculated Q angle and the magnitude of FMEDIAL ($P < .001$), such that over the range of Q angles studied (8.7–25.4°) FMEDIAL nearly tripled from 15% to 43% of the force in the quadriceps muscle. The intercept was statistically significant ($P < .001$) but trivial in comparison with the regression line gradient at 0.5% (95% CI: 0.3%, 0.7%). The correction for the offset of the rectus femoris muscle on F_{MEDIAL} was minor in effect, producing absolute increases of 0.04% to 0.5% compared to zero correction.

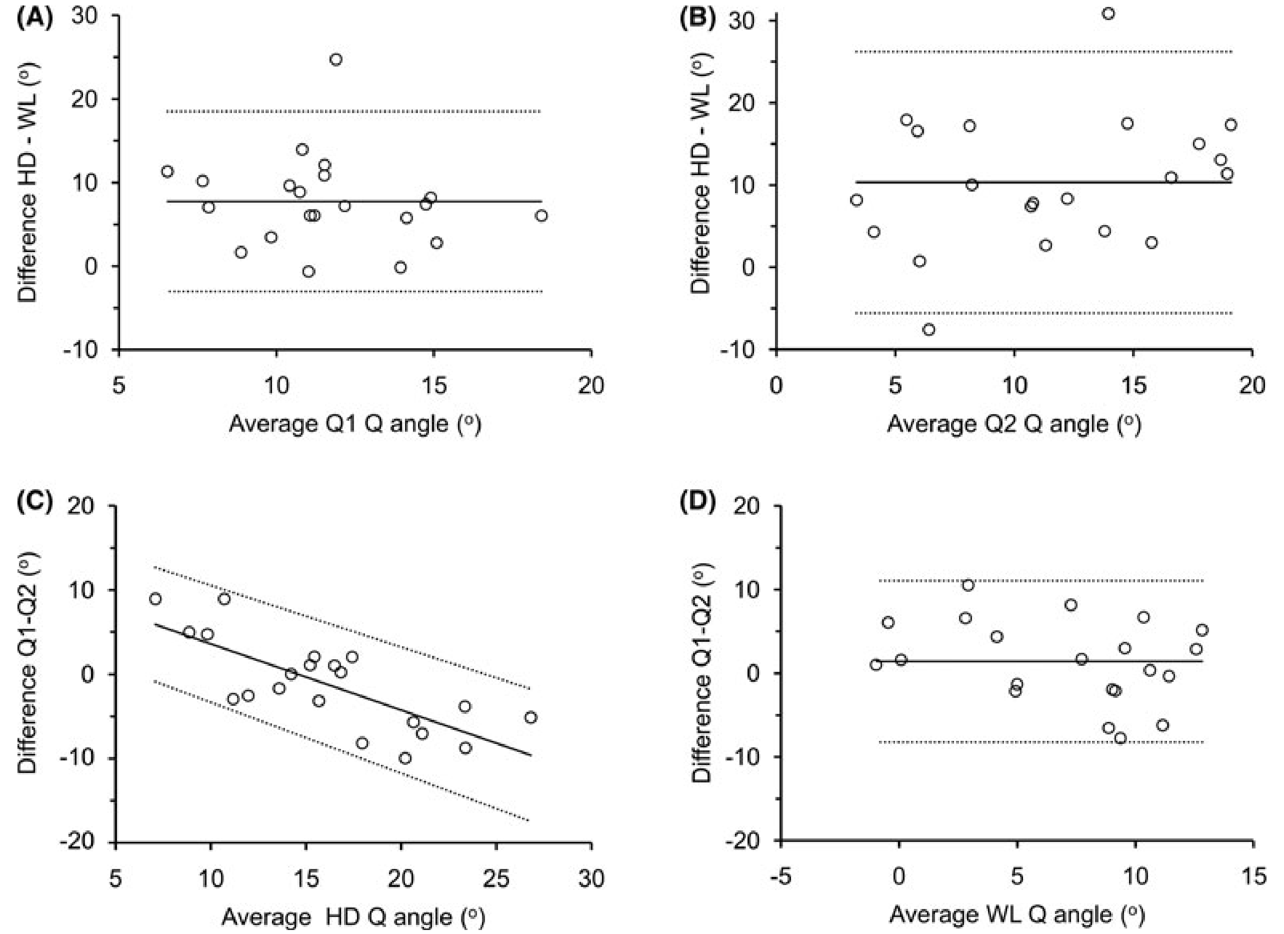

Figure 3 Bland–Altman difference plots to compare positioning techniques (A,B) and measurement techniques (C,D). Differences between 2 values are plotted against the mean of the 2 values. The solid line represents the bias (mean difference) and the dotted lines the 95% limits of agreement.

Reliability

Separate $ICC_{(2,k)}$ values were calculated for Q1 and Q2, however pooled values are presented since there was no significant difference between the 2 measurement techniques ($P > .05$). For the intraobserver comparisons, $ICC_{(2,3)}$ values were 0.99 (95% CI: 0.98, 0.99) for observer JM and 0.98 (95% CI: 0.97, 0.98) for observer JVF, indicating substantial intraobserver agreement. Values for the within-subject standard deviation and coefficient of reliability were significantly lower for Q1 than Q2 in all cases ($P < .001$), and significantly lower for observer JM in all cases ($P < .05$) except for the Q2 coefficient of reliability ($P = .05$). For observer JM, within-subject standard deviations were 0.88° (95% CI: 0.78°, 0.97°) and 1.9° (95% CI: 1.7°, 2.1°), and coefficients of reliability were 2.5° (95% CI: 2.2°, 2.7°) and 5.4° (95% CI: 4.8°, 6.0°) for Q1 and Q2, respectively. For observer JVF, within-subject standard deviations were 1.0° (95% CI: 0.93°, 1.2°) and 2.3° (95% CI: 2.0°, 2.5°), and coefficients of reliability were 2.9° (95% CI: 2.6°, 3.2°) and 6.3° (95% CI: 5.7°, 7.1°) for Q1 and Q2, respectively.

For the interobserver comparison, the $ICC_{(2,2)}$ value was 0.96 (95% CI: 0.94, 0.98), slightly lower than for either intraobserver value but still indicating substantial agreement. The within-subject standard deviations were slightly increased compared with the intraobserver values at 1.1° (95% CI: 1.0°, 1.3°) and 2.5° (95% CI: 2.3°, 2.8°), as were the coefficients of reliability at 3.2° (95% CI: 2.9°, 3.6°) and 7.0° (95% CI: 6.3°, 7.9°) for Q1 and Q2, respectively, confirming slightly less agreement.

The coefficients of reliability are defined as the maximum expected difference between 95% of pairs of measurements because of measurement error: in this they effectively determine the minimum difference that could be detected experimentally. The coefficient of reliability for Q1 was consistently less than half the size of that for Q2, indicating that Q1 is a more sensitive measurement than Q2. Transferring the coefficients to the error model suggests an expected maximum uniform error in coordinate selection at the 3 locations (acetabular lip, patellar center or trochlea, and tibial tuberosity) of 0.41 mm for Q1 and 0.54 mm for Q2 between 95% of pairs of measurements on the same patient.

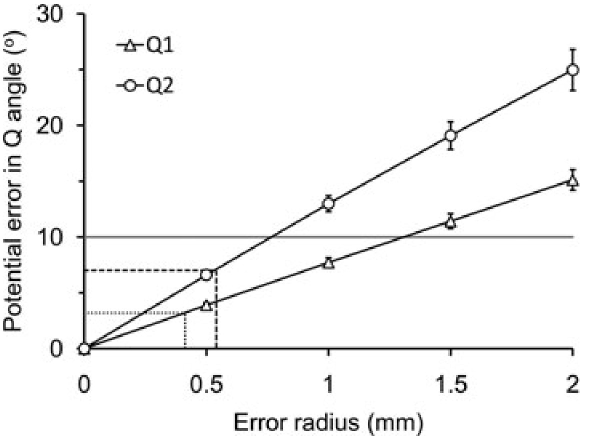

Figure 4 Variation in mean potential Q angle error with increasing error radii, for the 2 Q-angle techniques Q1 and Q2 for the HD limb position. Positional errors of equal magnitude have been applied at the cranial acetabular lip, patellar center, and tibial tuberosity. The potential error is the difference between the maximum and minimum Q angle achieved with a given positional error magnitude. The maximum permissible 10° error range suggested by France et al.[15] is shown (gray line). Lines for the coefficient of repeatability for Q1 (3.2°, dotted) and Q2 (7.0°, dashed) are shown, to highlight the likely positional error between 95% of measurement pairs (0.41 mm and 0.54 mm for Q1 and Q2, respectively). Error bars represent 95%CI .

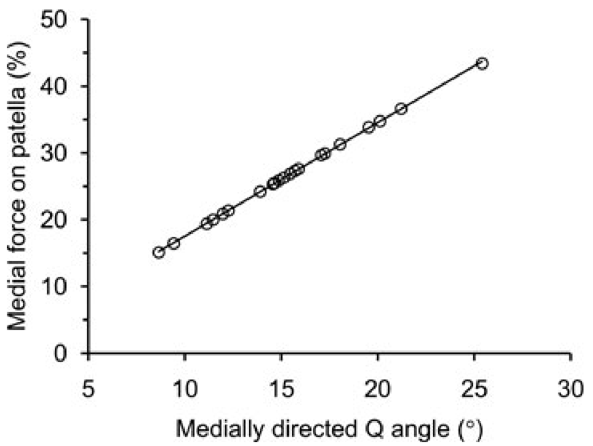

Figure 5 The effect of Q angle magnitude on medial force developed at the patella. Q angles were calculated from coordinate data, and the medial force determined trigonometrically as a percentage of quadriceps force (Fig 2). Each degree increase in Q angle resulted in a 1.7% increase in medial force ($P < .001$, SE = 0.006). The correlation coefficient (R^2) was 0.99 and the residual standard deviation was 0.10.

DISCUSSION

Key findings from this study were the significant differences in Q angle values between the 2 radiographic positions and the poor agreement between the 2 measurement techniques. We demonstrated that measurements could be made with substantial agreement within and between observers, but that the potential for error remains large, especially with the Q2 measurement. In addition this study showed that the magnitude of the Q angle can have a profound effect on the lateromedial forces at the level of the patella.

For both the HD and WL positions, the mean Q1 values were significantly more medial than the Q2 values (by 8.2 and 11.5, respectively). This difference is clinically significant, if the results of Q angle measurement are to be used to guide surgical intervention for correction of medial patellar luxation, because it results in a large variation in the calculated reference intervals. Because we corrected for hip rotation and therefore movement of the acetabular rim point between the HD and WL positions, this difference is solely because of reduced internal rotation of the tibia relative to the femur in the WL position compared to the HD position. In our department, HD position radiographs are positioned manually, and considerable torque may be applied to the distal limb to achieve an acceptable image. This torque is likely to result in the maximum possible internal rotation for the extended stifle. In contrast the WL position requires a minimal torque to the distal limb to stabilize the femur and stifle, because only 1 limb is radiographed at a time. The internal rotation produced might be expected to be less predictable and result in an increase in measurement variance: the standard deviations for the WL position were, however, only slightly increased for Q1 and slightly reduced for Q2. This suggests that internal rotation was fairly constrained in the study population.

An alternative method of achieving the HD position without manual restraint involves taping the femora at the level of the stifle and extending the limbs with ties.[14] Although we did not test this technique, it is likely to yield results closer to the WL position than the HD position, because little or no torque is applied to the distal limb. It is important, therefore, to be aware of which positioning technique has been used to produce the Q angle measurement before making any comparisons with published data. From a clinical viewpoint, it could be argued that the WL position better reflects the normal physiologic relationship of the quadriceps mechanism components, since the HD position is a stressed situation. Our experience of medial patellar luxation patients is that the lateral restraints to internal rotation of the stifle are often much laxer than those of normal dogs. Consequently, the worst case situation for these dogs is better represented by the HD position measurements. How either position relates to the situation in the standing patient has not been investigated for either dogs or foxes.

Despite the statistically insignificant difference observed between Q1 and Q2, the 2 measurements cannot be considered equivalent, as is clearly demonstrated by the Bland–Altman difference plots. The bias for the HD position varies with the Q angle, and in both HD and WL positions the limits of agreement between Q1 and Q2 were unfavorably wide in comparison with the calculated reference intervals. Consequently the 2 measurement techniques cannot be used interchangeably, nor can values and reference ranges be compared between techniques.

Kaiser et al.[9] defined the midpoint for the Q angle measurement as the deepest part of the trochlea at the level of the mid-patella, which should correspond to the midpoint of the patella in stifles without a medially luxated patella. This yields a Q angle equivalent to the Q1 technique used in our study and provides for a 95% reference interval in normal dogs of −0.7–21.7°, assuming a normal distribution.[9] Our Q1 ranges are consistent with, and tighter than, this interval. Even if the normal values from Kaiser et al. showed a similar reduced variance, they would still overlap with calculated 95% reference intervals for affected dogs (grade 1: −4.8–29.7°; grade 2: 2.5–46.1°; grade 3: 19.4–53.8°).[9] Our ranges remain wide despite the homogenous population, suggesting that the variation in Q angles previously reported for normal and affected dogs is unlikely to be significantly improved by consideration of breed or size.

A useful extension to this study would have been to obtain a series of radiographs after repeated repositioning, as the amount of internal rotation created may not be constant for each individual in each position. The error model gives some indication of the variation in measured Q angle that can be expected if positioning is not identical between exposures.

Although no significant difference between left and right limbs was evident by comparison of the means, comparison of intra-individual differences showed that left and right limbs can have markedly different Q angle measurements. Similar findings have been reported for human subjects, possibly because of the effect of limb dominance.[24] We did not identify a trend toward greater Q angles for one side that might be comparable with the findings in people. Nevertheless, it cannot be assumed that Q angles in dogs will be symmetric.

We did not observe a statistically significant gender difference in Q angle. Gender differences are noted in people, but this appears to be related to height differences.[25] Sexual dimorphism in height has been reported in dogs.[26] Similar Q angle differences might occur between dogs of different heights because of breed or because of marked sexual dimorphism within breeds.

Error modeling helped to identify where particular care should be taken during measurements. Our findings correlate well with those from a human model.[15] The ranges identified in the simulation are worst cases, but give an indication of the potential for uncertainty depending on measurement technique and positioning. In people, a location error of the patellar center and tibial tuberosity of <2 mm has been recommended to reduce Q angle error to below ±5°.[15] Based on data shown in Fig 5, the 3 measurement landmarks need to be defined within 1.3 mm (Q1) or 0.8 mm (Q2) to achieve this level of accuracy. This recommendation is dependent on the patient size: the smaller the patient, the more critical location accuracy becomes. As our results indicate, this level of accuracy is achievable.

The extent to which the potential for error affects the inter-individual variance apparent in our results and those of others is uncertain. The low intra- and interobserver differences in this study despite the modeled error can probably be attributed to the ease and accuracy with which a small radiographic image can be magnified and measured with the appropriate software.

Increasingly medially directed Q angles result in significant increases in the medial force exerted on the patella as a result of quadriceps contraction. This force must be resisted by the soft tissue and bony constraints to lateromedial translation of the patella to prevent luxation, and is predicted to reach equivalence with the quadriceps force when the Q angle is ∼59°, 8° more medial than the maximum reported angle for grade 3 medial patellar luxation.[9] The range of Q angles and associated F_{MEDIAL} values in these normal foxes was large, which suggests that consideration of the Q angle in isolation as a cause of medial patellar luxation would be simplistic. Further investigation to relate local anatomic factors such as trochlear depth and shape, femoral rotation, patellofemoral ligament thickness, and more global factors such as limb positioning during standing and walking to the Q angle may enable a more holistic evaluation of the stifle affected by medial patellar luxation.

Intra- and interobserver agreement was substantial, based on the calculated $ICC_{(2,k)}$ values. The ICC relates variability between subjects to variability within subjects. While the large standard deviations observed in this study may have increased the ICC values reported and masked any apparent difference in reliability between the 2 observers,[27] consideration of the within-subject standard deviation and the coefficients of reliability show there was no clinically significant difference in reliability between the experienced and inexperienced observers. This implies that the methods described here could be readily employed in practice. In the observers' opinion, the use of digital imaging software with the ability to magnify areas of interest and employ false color spectra to improve identification of key points was a benefit. The Q1 measurement was clearly more reliable than Q2, based on the within-subject standard deviation and coefficient of reliability. Use of the intercondylar notch as a reference point for Q2 resulted in increased variance compared with use of the patellar center (Q1), particularly in the HD position. Geometrically, the closer proximity of the intercondylar notch to the tibial tuberosity necessarily results in a wider range of angles for Q2 than for Q1. This is reflected in the error modeling, which predicts larger potential angular errors for any given positional error for Q2 compared with Q1: a 119% (3.8°) increase in coefficient of reliability from Q1 to Q2 was associated with only a 32% (0.13 mm) increase in the positional error. Conversely, in clinically affected animals it should be possible to more accurately define the radiographic position of the intercondylar notch than that of the patellar center, because of the risk of subluxation or luxation of the patella.

This study identified a number of issues with the use of the Q angle. Direct comparison of measurements made using the Q1 and Q2 techniques is unreliable. The Q angle depends acutely on the amount of internal rotation developed at the stifle during radiography, which could make accurate comparison between studies difficult. Despite the use of a homogenous population in this study, the 95% reference intervals are very wide making it difficult to define a normal Q angle. The large potential errors inherently associated with misidentification of the center of the patella or intercondylar notch risk introducing considerable inaccuracy into Q angle determination, especially when the Q2 technique is used.

Summarily, radiographic Q angle measurement may be useful in conjunction with other assessment criteria but should not be used alone for objective assessment of medial patellar luxation.

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