Computed Tomographic Measurement of Trochlear Depth in Three Breeds of Brachycephalic Dog

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Abstract

Objective The aim of this study was to determine the trochlear sulcus depth of three common brachycephalic breeds at risk of medial patellar luxation.

Study Design Retrospective blinded clinical study using a previously validated ratio (T/P) of maximal trochlear sulcus depth (T) and maximal patellar craniocaudal thickness (P) measured on computed tomography, to assess trochlear sulcus depth in Pugs, French Bulldogs and English Bulldogs without clinical patellar luxation. The effect of breed on T/P was assessed using one-way linear regression models.

Results The mean T/P was affected by breed ($p < 0.001$). There was significant difference between Pugs (0.45) and French Bulldogs (0.38) and between Pugs and English Bulldogs (0.4). There was no significant difference between Pugs and previously published data for non-brachycephalic and mixed breed dogs (0.46) ($p = 0.39$). Mean T/P was significantly reduced in the brachycephalic dog breeds combined compared with the previously published data ($p < 0.001$).

Conclusion The trochlear sulcus varies by breed and was more shallow in French and English Bulldogs than Pugs, hence a shallow sulcus may be a breed-driven characteristic. The three breeds assessed are at risk of patellar luxation but sulcus depth did not directly correlate with previously published risk factors—the contribution of sulcus depth to the aetiopathogenesis of patellar luxation remains unclear. Trochlear recession to achieve patellar coverage of 50% may be excessive considering maximal breed normal depth.

Keywords
- patellar luxation
- brachycephalic dog
- femur
- trochlear sulcus
- computed tomography

Introduction

Medial patellar luxation is a common developmental condition associated with a combination of anatomical abnormalities affecting different individuals with varying severity.[1–3] The prevailing theory of the aetiology is a medial displacement of the quadriceps femoris due to coxa vara and a diminished anteversion angle of the femoral neck.[4,5] This leads to a femoral varus, external femoral torsion and internal rotation of the tibia and medial displacement of the tibial tuberosity during development.[2] The resultant misalignment of the trochlea and patella reduces retropatellar pressure on the developing trochlear sulcus potentially leading to a shallow or absent

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sulcus.[2,3] However, the evidence for this sequence of events is lacking, and this sequence does not account for why some dogs develop a clinical patellar luxation in later adulthood.

Most dogs with clinically apparent patellar luxation have some degree of insufficiently deep trochlear sulcus.[6–8] Slocum suggested that the sulcus should be able to accommodate around 50% of the cranial to caudal depth of the patella,[9] and several deepening trochleo/sulcoplasty procedures have been described and used widely over the years.[2,10] However, some have advocated correcting other components of patellar luxation without a sulcoplasty to deepen the groove,[11] questioning the necessity of a procedure which lengthens surgery time and may predispose to osteoarthritis.[12] To date, the association of breed specific abnormalities of the trochlear sulcus and the prevalence of patellar luxation has not been investigated.

The popularity of brachycephalic breeds such as Pugs, French Bulldogs and English Bulldogs has greatly increased over the past 10 years in the United Kingdom.[13,14] In an investigation of the prevalence of patellar luxation in the United Kingdom, based on 210,824 dogs, 50% of the 14 breeds with the highest risk for patellar luxation were brachycephalic, with French Bulldogs being most common followed by the Lhasa Apso, Cavalier King Charles Spaniel, Pug, English Bulldog, Shih Tzu and Staffordshire Bull Terrier.[1]

A method of measuring trochlear sulcus depth using computed tomography (CT) has been previously validated and published.[15] The study comprised nine non-brachycephalic pure breeds (11 dogs) and crossbreed dogs (9 dogs) of skeletal maturity without medial patellar luxation. An index of trochlear depth for each stifle was determined using a ratio of maximal trochlear sulcus depth and maximal craniocaudal patellar thickness (T/P ratio). The mean T/P ratio was 0.46 which represents a patellar coverage of 46% by the trochlear ridges at the point of mean maximal trochlear sulcus depth and mean maximal patellar thickness. The authors recommended further investigation to determine breed specific trochlear depth measurements which may be important when performing trochlear sulcus recession as a component of patellar luxation surgery. Currently, it is recommended that trochleoplasty is performed for dogs with a shallow sulcus, with the aim of achieving 50% coverage of the maximal patellar depth by the trochlear ridges, based on an estimated coverage of 50% in normal dogs.[9] This recommendation is unsubstantiated but commonly cited.[2,3,16]

This study aimed to determine the trochlear sulcus depth in three common brachycephalic breeds noted to be at an increased epidemiological risk of patellar luxation.[1] The hypothesis was that at-risk brachycephalic breeds would have a significantly reduced maximal trochlear sulcus depth than the previously published non-brachycephalic and mixed breed dogs. It was also hypothesized that the brachycephalic breeds at highest risk would have the shallowest trochlear sulcus.

Materials and Methods

Inclusion Criteria

Medical records were retrospectively reviewed for Pugs, English Bulldogs and French Bulldogs undergoing CT imaging between 2014 and 2017. Patients were included if they were presented for a non-orthopaedic complaint, were at least 1 year of age and had CT imaging of the femur including the stifle. Cases were excluded if a full clinical examination was not recorded, if there was gross angular limb deformity noted clinically or on CT, if patellar luxation or subluxation was identified from the clinical records or on CT, or if there was evidence of stifle osteoarthritis on CT. Data recorded from the clinical records included case number, breed, age at scan, gender, neuter status, bodyweight and salient diagnoses. Ethical approval was granted by the institutional ethics committee (URN SR2019–0313).

Imaging

Scanning was performed using a 16-slice CT scanner (Philips MX8000 IDT, Guildford, Surrey, United Kingdom) with a 0.75mm detector width. Scans were acquired helically with 1, 1.5 or 2 mm slice thickness and 0.5, 1.0 or 1.5 slice overlays, dependent upon when the case was presented within the study period.

CT Measurements

Three-dimensional multiplanar reconstruction was performed using advanced DICOM viewing software (Horos, v.3.3.5, Purview, Annapolis, Maryland, United States). Measurements of trochlear depth (T) and patellar maximal craniocaudal thickness (P) were obtained as previously described and validated.[8] The ratio between T and P (T/P ratio) was calculated with a value of 0 representing an absence of the trochlear sulcus and a value of 1 representing 100% coverage of the patella within the trochlea. A single measurement was obtained for each stifle by a single blinded observer (A.M.).

Statistical Analysis

The measurements for the right and left stifle of each dog were analysed as independent if both stifles from the same patient were included. Data were analysed using R (version 3.5.3, 2019; R Foundation for Statistical Computing, Vienna, Austria). Level of significance was set at $p < 0.05$. Data were assessed for normality using frequency histograms and the Shapiro–Wilk test. Continuous explanatory variables were reported as mean and standard deviation and non-parametric data as median, interquartile range (IQR) and range (minimum-maximum). The non-parametric variable age was grouped into two categories: $\leq$2 years and $>$2 years. The effect of each of the explanatory variables (breed, sex, neuter status and age category) on T/P was assessed by linear regression. Weight was related to breed and not included as an explanatory variable.

Previously published results for maximal T/P ratio in non-brachycephalic and mixed dog breeds were compared with the collected data.[8] In the previous study, stifles were measured nine times to produce nine values for T/P to investigate intra and inter-observer agreement. The mean average of these measurements was used for comparison in the current study.

Results

Age and T/P ratio were not normally distributed (Shapiro–Wilk normality test $p \leq 0.001$ and $p = 0.017$ respectively). Younger dogs were over-represented, hence recategorization of age as above. T/P ratio was transformed by natural logarithm to achieve normality (Shapiro–Wilk test $p = 0.12$).

Pugs

Sixteen Pugs were included (31 stifles). Median age was 2.96 years (range: 1.56–6.58 years, IQR: 2.39 years) and median weight was 9.4 kg (range: 7–12.4 kg, IQR: 2.05). Weight was not recorded for one dog. Mean T/P ratio was 0.45 (range: 0.38–0.56, IQR: 0.07). Twelve Pugs were presented primarily for the treatment of brachycephalic obstructive airway syndrome or for problems directly related to brachycephalic obstructive airway disorder. Two Pugs were each presented for otitis media, lumbosacral disease, entropion and oronasal fistula as the primary condition and were then referred for brachycephalic obstructive airway disorder correction.

French Bulldogs

Eighteen French Bulldogs were included (34 stifles). Median age was 1.66 years (range: 1.02–6.03 years, IQR: 1.79 years) and median weight was 12.0 kg (range: 8.7–16.1 kg, IQR: 2.8). Weight was not recorded for one dog. Mean T/P ratio was 0.38 (range: 0.29–0.48, IQR: 0.06). Fifteen French Bulldogs were presented for brachycephalic obstructive airway disorder correction or for problems directly related to brachycephalic obstructive airway disorder. Two dogs were presented primarily for otitis media and one was presented for temporomandibular joint misalignment and were then referred for brachycephalic obstructive airway disorder correction.

English Bulldogs

Eighteen English Bulldogs were included (33 stifles). Median age was 1.64 years (range: 1.03–6.61 years, IQR: 1.6 years) and median weight was 24.5 kg (range: 10.3–34.6 kg, IQR: 6.9kg). Weight was not recorded for one dog. Mean T/P ratio was 0.40 (range: 0.30–0.56, IQR: 0.08). Sixteen English Bulldogs were presented for brachycephalic obstructive airway disorder or for problems directly related to brachycephalic obstructive airway disorder. Two dogs were presented primarily for entropion and subsequently had brachycephalic obstructive airway disorder correction.

Analysis

On one-way model analysis of the data collected in this study, there was no effect of sex ($p = 0.29$), neuter status ($p = 0.18$) or age ($p = 0.17$) on T/P ratio. French and English Bulldogs had a significantly reduced mean T/P ratio than Pugs ($p \leq 0.001$ for both), representing on average a shallower trochlear sulcus in Bulldogs. There was no significant difference between French and English Bulldogs ($p = 0.36$).

When the three brachycephalic breeds were each individually compared with previous data from the group of non-brachycephalic and crossbreed dogs, English Bulldogs and French Bulldogs had a significantly lower mean T/P ratio ($p \leq 0.001$ for both).[8] Pugs had a lower ratio (0.45) than the previously published data (0.46) but this was not significant ($p = 0.39$) (►**Fig. 1**; ►**Supplementary Table S1** [available in the online version]). The T/P ratio in Pugs (0.45) was not significantly different to previously published data (0.46) ($p = 0.39$).

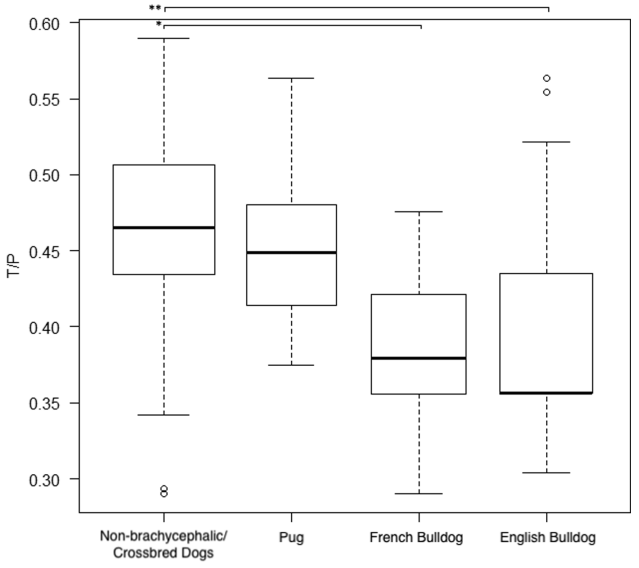

Fig. 1 Box and whisker plot of T/P ratio for Pugs, French Bulldogs, English Bulldogs and non-brachycephalic/crossbreed dogs.[15] The effect of breed was assessed by linear regression analysis with breed 4 as the reference level. T is maximal trochlear depth and P is maximal craniocaudal patellar thickness, * and ** are significantly different from the reference level ($p \leq 0.001$).

When the data for the three brachycephalic breeds were combined and compared with the data for non-brachycephalic and crossbreed dogs,[8] the brachycephalic group had a significantly lower mean T/P ratio ($p \leq 0.001$) (►**Fig. 2**, ►**Supplementary Table S2** [available in the online version]).

Discussion

Trochlear sulcus depth was assessed using a previously validated ratio of maximal trochlear depth to maximal patellar craniocaudal thickness.[15] Overall, the three brachycephalic groups assessed here had a significantly shallower sulcus than the non-brachycephalic breeds. When examined individually, French and English Bulldogs had a significantly shallower sulcus than Pugs and non-brachycephalic breeds.[15] Interestingly, Pugs, which are an at-risk breed for patellar luxation, had a similar trochlear sulcus depth to non-brachycephalic and crossbreed dogs.[1] When Petazzoni and colleagues evaluated maximal T/P in crossbreed dogs, there was a wide variation in T/P with a range difference of 0.30, which led them to recommend breed specific measurements. The brachycephalic breed T/P ratios also showed variation, but this was reduced with a breed range of 0.19 for Pugs, 0.19 for French Bulldogs and 0.26 for English Bulldogs, indicating that breed T/P ratios are appropriate. Some degree of individual variation within a breed is likely to be expected, and its relationship to patellar luxation should be investigated by comparison with clinically affected dogs.

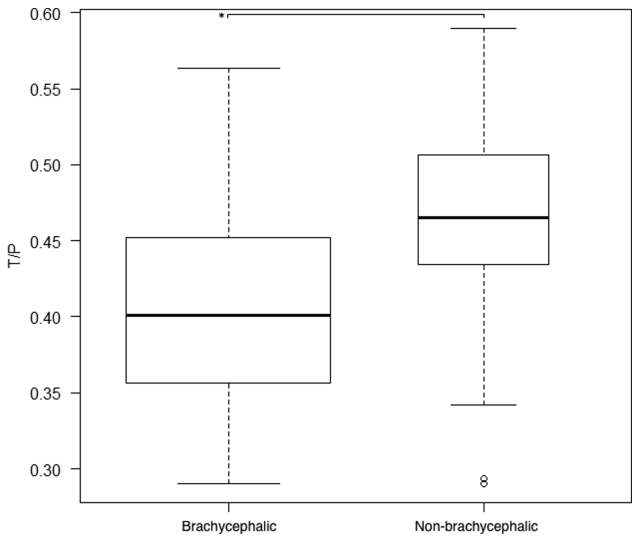

Fig. 2 Box and whisker plot of T/P ratio for brachycephalic breeds combined and non-brachycephalic/crossbreed dogs.[15] The effect of breed type was assessed by linear regression analysis. T is maximal trochlear depth and P is maximal craniocaudal patellar thickness, * is significantly different from the reference level ($p \leq 0.001$).

Trochlear sulcus depth contributes to the stability of the patella.[2–4,17–19] The three brachycephalic breeds examined here had an epidemiological risk factor for patellar luxation and two breeds had evidence of a hypoplastic trochlear sulcus.[1] The dogs examined in this study were unaffected by patellar luxation and no causal link for the condition can be directly established, but it is conceivable that clinically affected dogs may have had further reduced trochlear sulcus depth. On an individual basis, it was not possible to longitudinally determine if and how many of the dogs presenting for brachycephalic obstructive airway disorder developed patellar luxation later in life. This study did not compare dogs with and without medial patellar luxation; however, we speculate that the breed predisposition of French and English Bulldogs to patellar luxation may be at least partially related to trochlear depth. As Pugs are also a breed at risk[1] but did not appear to have a significantly shallower sulcus, this could indicate that different breeds may have varying severities of the components that drive patellar luxation. Comparison of these data with clinically affected dogs of each breed is necessary to determine the role of sulcus depth in the aetiology of patellar luxation.

The widely acknowledged hypothesis for the aetiology of medial patellar luxation is extrapolated from human medicine and remains unproven, whereby a reduced angle of femoral neck anteversion drives external rotation of the coxofemoral joint, and subsequent soft-tissue and skeletal changes.[4] The resultant loss of patellar retropatellar force within the trochlear sulcus is proposed to affect the sulcus formation; however, patellar luxation presents clinically as a spectrum of disease and there is considerable variation in trochlear sulcus depth evident at surgery.[18] Patellar luxation can occur in dogs with a relatively well-formed sulcus, hence the advocation of omitting trochleoplasties in some cases.[11] This suggests perhaps that there may be different routes to develop patellar luxation, with more severe grades differing from less severe grades. Despite the fact that a shallow trochlear sulcus is well reported in dogs with patellar luxation, no studies have correlated the depth of the trochlear sulcus with the grade of patellar luxation.[5,9,11,20,21] Some skeletal abnormalities have been more thoroughly evaluated, but the findings have been contradictory.

Coxa vara, relative retroversion of the femoral neck and distal femoral varus (using the angle of inclination, angle of anteversion, anatomical lateral distal femoral axis and femoral varus angle respectively), have been assessed in dogs with and without medial patellar luxation.[22–24] Significant differences could be identified in high-grade patellar luxations (grades III–IV/IV) but not between unaffected dogs and those with low grade I to II/IV medial patellar luxation.[25] A further study of 18 dogs (predominantly Poodles) with medial patellar luxation found no difference in the inclination angle or femoral varus angle between different grades of luxation and included 15/31 stifles with grade III or IV luxations.[26] Furthermore, examination of the anteversion angle in 84 pelvic limbs (33 with patellar luxation) found no significant difference between luxation grade and anteversion angle.[27] Overall therefore, the aetiology remains unclear and potentially differs by severity. Other theories include a hormonally driven aetiopathogenesis, as oestradiol administration to puppies in a controlled study resulted in a significantly shallower trochlear sulcus 8 weeks later, with 4 of 6 test subjects having a degree of patellar luxation (grade I–II/IV) compared with none of the controls.[17] In another study, severe atrophy and fibrosis of the quadriceps femoris were identified in puppies less than 8 weeks old with medial patellar luxation, most obvious in rectus femoris.[28]

The brachycephalic breeds in this study had a significantly reduced trochlear depth compared with non-brachycephalic breeds and there was variation between Pugs, English and French Bulldogs. Variation in craniofacial conformation in brachycephalic dog breeds has been reported along with spinal malformations but variation in appendicular conformation has not been well described.[29,30] It is possible, therefore, that the chondrodystrophic nature of brachycephalic breeds predisposes them to orthopaedic disease due to their associated limb conformation. This study corroborates the suggestion that maximal trochlear depth varies by breed[15] however, whether or not the more shallow sulcus in brachycephalic breeds is associated with appendicular morphology that predisposes to patellar luxation remains unknown.

When performing surgical correction of patellar luxation, the current recommendation for trochleoplasty depth is 50% of the maximal patellar craniocaudal thickness.[9] In this study, the mean ratio across the three breeds was 0.41 with 92% of stifles having a ratio less than 0.5. This suggests returning some dogs with patellar luxation to a 'breed-normal', a 50% trochleoplasty may be unnecessary and potentially undesirable and a breed specific adjustment may be more appropriate. It conceivable that excessive recession of the trochlear sulcus, particularly if the block was not as wide as the patella, could result in a sulcus which does not centrally support the overlying patella, with hitherto unknown consequences. It should also be considered

that the site of T/P measurement was at the deepest point of the trochlear sulcus, but this does not account for any potential variation in sulcus depth along the length of the trochlea, with some grooves possibly having a greater differential between the shallowest and deepest measurements.[15] A CT cadaveric study comparing block and wedge resection sulcoplasties identified that despite having equal mid trochlear depth, a shallower proximal groove as a result from a wedge resection was more prone to luxation.[10] However, this outcome may relate more to the resultant geometry of the linear intersecting sections of the wedge when made along the curved sulcus. A block recession sulcoplasty, on the other hand, uniformly deepens the trochlear sulcus and reduced luxation of the proximally positioned patella, suggesting that groove depth may be somewhat uniform over its length. Further work is needed to evaluate the relationship of maximal T/P and sulcus depth over its length and whether it differs between dogs with and without patellar luxation.

Clinical experience of lower grade patellar luxations also corroborates many luxations manifesting over the proximal portion of the groove; however, this study design does not account for the influence of patellar position within the groove. Petazzoni and colleagues, commented that to provide guidance on when and where to perform a sulcoplasty, then a measure of T/P with the stifle hyperflexed and hyperextended, in addition to maximal T/P would be highly useful. Patella alta has been associated with medial patellar luxation in medium and large breed dogs,[31] however not in small breeds where patellar position did not influence patellar luxation.[32] These types of studies logically lead to breed determination of patellar positioning or even individual dog preoperative assessment of patellar position combined with breed standard trochlear groove depth to provide the most appropriate and individualized correction.

A limitation of this study is the inability to assess cartilage thickness on CT. Individual or breed variation in cartilage thickness of the trochlear sulcus would affect the depth of the trochlear sulcus clinically and consequently the development of an intraoperative assessment of trochlear depth would need to account for this. Placing a bone plate across the trochlear ridges to enable trochlear sulcus depth measurement with a depth gauge has been described, but was unreliable.[18] Further limitations include the retrospective nature of this study and the relatively low case numbers which could generate type II statistical errors, although these sample sizes were consistent with the previous study.[15] Additionally, this study had a range of slice thickness and slice overlaps, although all were equal to or thinner slices with closer overlap than the Petazzoni study.[15] It has been shown that thinner slices provide more accurate three-dimensional measurements; however, the change in volume under-measurement between a 0.625 and 1.25 sliced scan is relatively small at 4%,[33] and hence unlikely to influence the measurements in this study.

This study is the first to determine the influence of breed on trochlear sulcus depth. It partly confirmed the hypothesis that brachycephalic breeds at risk of patellar luxation have a shallower sulcus; however, the depth differed by the brachycephalic breed evaluated. Comparison to clinically affected dogs would help to determine whether sulcus depth is further reduced in clinical patellar luxation, or whether other contributing factors such as coxa vara, femoral neck anteversion, distal femoral varus, external femoral torsion and brachycephalic breed femoral procurvatum add to the breed shallow sulcus to result in patent luxation.

The work presented here has established breed specific T/P for three common brachycephalic breeds in dogs without patellar luxation. Although some variation in maximal T/P was seen, the variation was reduced from the mixed breeds evaluated previously.[15] Although this study cannot show a relationship, or causality for patellar luxation, it develops our understanding toward understanding this complex disease. Ultimately, the values for trochlear depth ratios in this study could form part of the basis to inform the determination of breed specific reference ranges and consequently impact on recommendations for breed appropriate trochleoplasties.

Authors' Contributions

B.M., M.P. and R.M. contributed to conception of the study; A.M., A.P. and R.M. designed the study; A.M., B.M. and R.M. acquired the data; and A.M., J.B. and R.M. contributed to data analysis and interpretation. All authors drafted/revised and approved the submitted manuscript. They are publically accountable for relevant content.

Conflict of Interest

None declared.

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