Original Article

Conventional vs Three-Dimensional Computed Tomography for Measurement of Tibial Tuberosity to Trochlear Groove Distance in Small Breed Dogs With and Without Medial Patellar Luxation

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Abstract

The operative technique for medial patellar luxation (MPL) is dependent on the degree of accompanying bone deformities. The most frequent abnormalities: the shallow trochlear groove and tibial tuberosity medialisation are corrected surgically with trochleoplasty and tibial tuberosity transposition, respectively. The aim of the present study was to determine the distance between the tibial tuberosity and the trochlear groove (TT-TG) on two-dimensional axial computed tomography (CT) scans and three-dimensional multiplanar reconstruction images from 21 stifles from healthy dogs and 15 stifles from dogs with grade 2 MPL and to compare the performance of both methods. Two axial CT scans of the tibial tuberosity and the entire femoral trochlea were selected to measure the TT-TG. The median TT-TG of healthy stifles was statistically significantly (P<0.001) shorter (1.4 mm on 2D and 1.3 mm on 3D images) compared to that of MPL stifles (2.1 mm on 2D and 2.3 mm on 3D images). 2D and 3D measurements showed good and excellent intra-rater agreement, respectively. TT-TG measured on 2D scans was compatible to that on 3D images. The measurement on single 3D images is easier and faster, permitting a more accurate identification of osseous landmarks. The preoperative measurement of the TT-TG distance would allow for more precise tibial tuberosity transposition surgery when indicated.

Keywords: computed tomography, medial patellar luxation, small dog breeds, tibial tuberosity-trochlear groove distance

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Introduction

Medial patellar luxation (MPL) is a developmental orthopaedic disease of multifactorial nature, common in dogs from small breeds (Bound *et al.*, 2009). It often occurs early in life and its progression is accompanied with complex musculoskeletal abnormalities affecting the development of pelvic limbs (Campbell *et al.*, 2010). The proper function of the stifle joints requires alignment of quadriceps femoris muscle, the patella, the trochlear groove, the patellar ligament and the tibial tuberosity. Any deviation of one or more of these elements displaces the strong quadriceps mechanism and results in medialisation of the tibial tuberosity (Hulse, 1995).

The effective surgical correction of MPL consists in realignment of the quadriceps mechanism responsible for contraction of quadriceps muscles and transfer of forces to the tibia for stifle joint extension and patellofemoral joint stabilisation (Lee *et al.*, 2020). The selection of an operative technique for MPL correction depends on the degree of accompanying bone deformities assessed on radiographs or computed tomography scans, and/or measurement of anatomical and mechanical femoral and tibial angles (Yasukawa *et al.*, 2016; Lusetti *et al.*, 2017). The commonest skeletal conformations: the shallow trochlear groove and tibial tuberosity medialisation are corrected surgically with trochleoplasty and tibial tuberosity transposition, respectively. Dogs with higher body weight and femoral varus angle exceeding 12° are suggested to necessitate corrective distal femoral osteotomy (Swiderski and Palmer, 2007).

In human orthopedics, the distance between the tibial tuberosity and the trochlear groove (TT-TG) is routinely used to evaluate the biomechanical risk in patellar dislocation along with abnormalities of bony stabilizers, trochlear dysplasia, and patella alta (Danielsen *et al.*, 2023). This diagnostic imaging parameter was proposed and described by Goutallier *et al.* (1978) on radiographs. The classical method of Dejour determines the TT–TG on axial computed tomography scans by superimposing sections through the deepest trochlear groove point and the most prominent point of the tibial tuberosity (Dejour *et al.*, 1994). The authors affirm that the TT-TG distance is essential in surgical approaches associated with transposition of tuberositas tibiae. To decrease the errors with superimposition of two sections, Koeter *et al.* (2007) proposed a new measurement technique, consisting in drawing lines on axial tibial groove image and their copy-paste onto the tibial tuberosity scan. The disadvantages of both measurement techniques are the facts that reference osseous landmarks needed for drawing of line are not always in the same axial plane; what is more, the identification of the deepest point of the three-dimensional trochlear groove arc may be challenging. That is why in several recent human studies, the 3D-CT imaging technique for the measurement of the TT–TG distance was suggested as a better technique providing more reliable and reproducible data (Okamoto *et al.*, 2016; Nha *et al.*, 2019; Beitler *et al.*, 2023).

In an earlier red fox cadaveric study, Miles *et al.* (2013) have described CT reconstruction criteria for measurement of the tibial tuberosity- trochlear groove distance (TT-TG), provided data on intra- and inter-reconstruction reliability of the parameter with analysis on the main sources of error in the measurement technique. To the best of our knowledge, such data in dogs are not reported.

The aim of the present study was to determine the distance between the tibial tuberosity and the trochlear groove (TT-TG) on two-dimensional and three-dimensional multiplanar reconstruction CT images in healthy dogs and dogs with medial patellar luxation and to compare the measurement performance of both methods.

Materials and Methods

Animals: This single-observer retrospective survey was performed in four small breeds with 21 healthy stifle joints and 15 joints with grade II medial patellar luxation.

The control group included 11 dogs (7 female and 4 male) referred to the clinic for minor interventions requiring anaesthesia, mostly dental procedures. The median age of dogs was 2.3 years (IQR 1.8 to 2.8 years). The breed distribution was 4 Mini Pinschers, 2 Pomeranians, 2 Chihuahuas, and 3 Yorkshire terriers. Both limbs of animals were measured. Inclusion criteria for the healthy joint group were absence of MPL in both limbs, absence of stifle degenerative joint disease, femoral or tibial limb deformity of both limbs, no asymmetry of femoral and gluteal muscles, and no signs of long-term proprioceptive dysfunction.

Joints included in the medial patellar luxation (MPL) group were from the same breeds (2 from Mini Pinschers, 3 from Pomeranians, 5 from Chihuahuas, and 5 from Yorkshire terriers). The animals were of similar age (median; IQR: 2.6; 2-3.8 years). Of them, 7 stifles were from female dogs and 8 – from male. For the MPL group, inclusion criteria were dogs with grade 2 MPL according to Putnam classification, absence of misshaped femoral trochlear groove (flat or concave), absence of stifle degenerative joint disease.

The differences between the two groups were not statistically significant with respect to breed (P=0.402); age (P=0.439), and sex (P=0.321).

Written informed consent for participation in the study was obtained from all dog owners.

Computed tomographic measurements: After deep i.m. sedation with 0.075 mg/kg medetomidine hydrochloride (Dorbene vet®, 1 mg/ml, Syva, Spain) and 7.5 mg/kg ketamine hydrochloride (Anaket®, 100 mg/ml, Richter Pharma, Austria), CT images were obtained in a distoproximal direction, with the dog in dorsal recumbency with extended pelvic limbs (OFA-view).

CT scans of the tibial tuberosity and the entire femoral trochlea were performed using a 32-slice CT scanner (Somatom Go Now, Siemens Healthcare GmbH, Erlangen, Germany) in a helical mode. Detector slice thickness was 1 mm, tube voltage: 120 kV, tube rotation time: 0.8–1 s, pitch: 0.6–1 with tube currents adjusted according to the size of the patient. The reconstructed slice thicknesses and increments were between 1 mm and 3 mm, allowing creating gapfree image stacks and continuous 3D CT data. Images were reconstructed using a bone algorithm. DICOM-images were imported into Syngo Via View & Go software (Syngo CT VA30, Siemens Healthcare GmbH, Erlangen, Germany).

All CT images were assessed by the author. For evaluation of intra-observer agreement, all 2D and 3D measurements were repeated after one month. To achieve measurements blinded to the specific patient, a technical assistant had anonymized the scans before each of two assessments.

Two CT scans were chosen for measurements: the TG scan was at the level of the "Roman Arch" at the top of the femoral condyle, at the deepest point of the femoral trochlea, and the TT scan: at the insertion center of the patellar tendon to the tibial tuberosity.

The TT-TG distance was measured on CT scans according to the method described by Koeter *et al.* (2007). The CT section through the trochlea (section 1) and the CT through the tibial tubercle (section 2) were aligned with section 1 brought in front of the two images (Fig. 1). First, line joining the posterior femoral condyles was drawn (reference red line a). A perpendicular to the reference line (red line b) was then dropped through the deepest point of the trochlear groove (landmark 1). Then, section 2 was brought in front and a second perpendicular (yellow line c) was dropped to the reference line through the most anterior point of the tibial tuberosity (landmark 2). The distance between the two perpendiculars is measured as the tibial tuberosity - trochlear groove distance (TT-TG) with a precision of 0.01 cm. Fig. 3 illustrates these measurements on 3D recontructed images from a heathy joint and a joint with patellar luxation.

Statistical analysis: Data are expressed as the median and interquartile range to the nearest hundredth of centimeter. The comparison between the two groups was conducted with the Mann-Whitney test. ICC estimate for absolute agreement was used for intra-rater reliability assessment and for comparison of the agreement between 2D and 3D results (Benchoufi *et al.*, 2020). ICC interpretation was: ICC< 0.5 - poor reliability, ICC of 0.5-0.75: moderate reliability, ICC of 0.75-0.9: good reliability and ICC > 0.90: excellent reliability. The two measurement techniques were also compared with Bland-Altman analysis. The respective scatter plot was drawn by MedCalc v12.1.3 (MedCalc Software, Belgium).

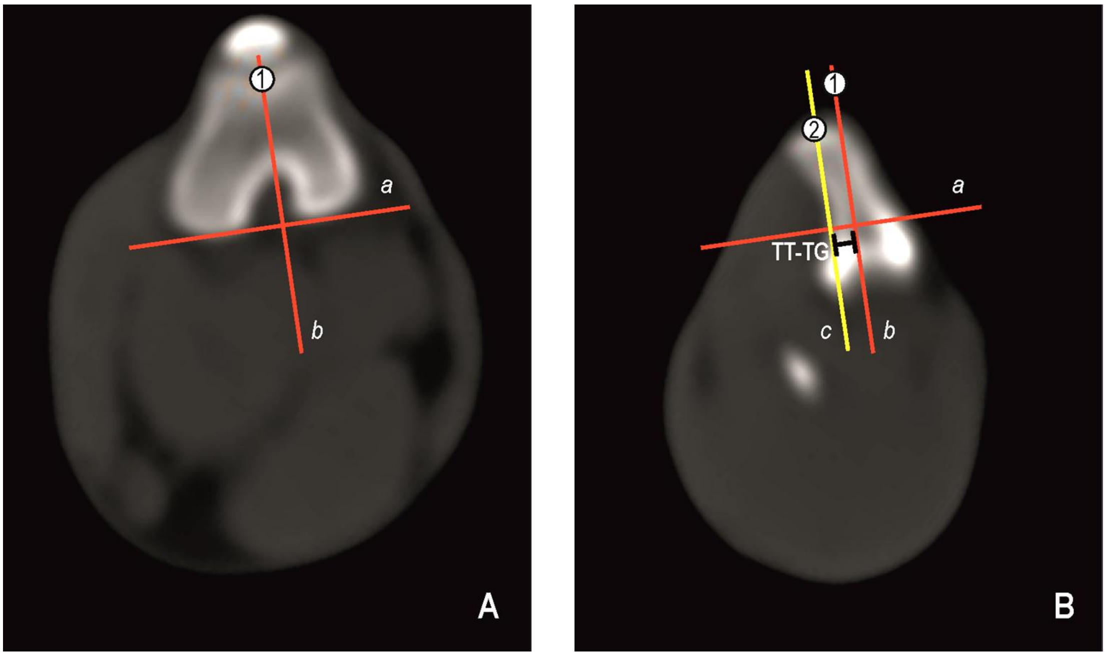

Figure 1 Conventional 2D measurement of the TT-TG distance: (A) The CT section through the trochlea (section 1) and the CT through the tibial tuberosity (section 2) are aligned with section 1 brought in front. A line joining the posterior femoral condyles is drawn (reference red line a). A perpendicular to the reference line (red line b) is then dropped through the deepest point of the trochlear groove (landmark 1). (B) Section 2 is brought in front and a second perpendicular (yellow line c) is dropped to the reference line through the most anterior point of the tibial tubercle (landmark 2). The distance between the two perpendiculars is measured as the tibial tubercle - trochlear groove distance (TT-TG).

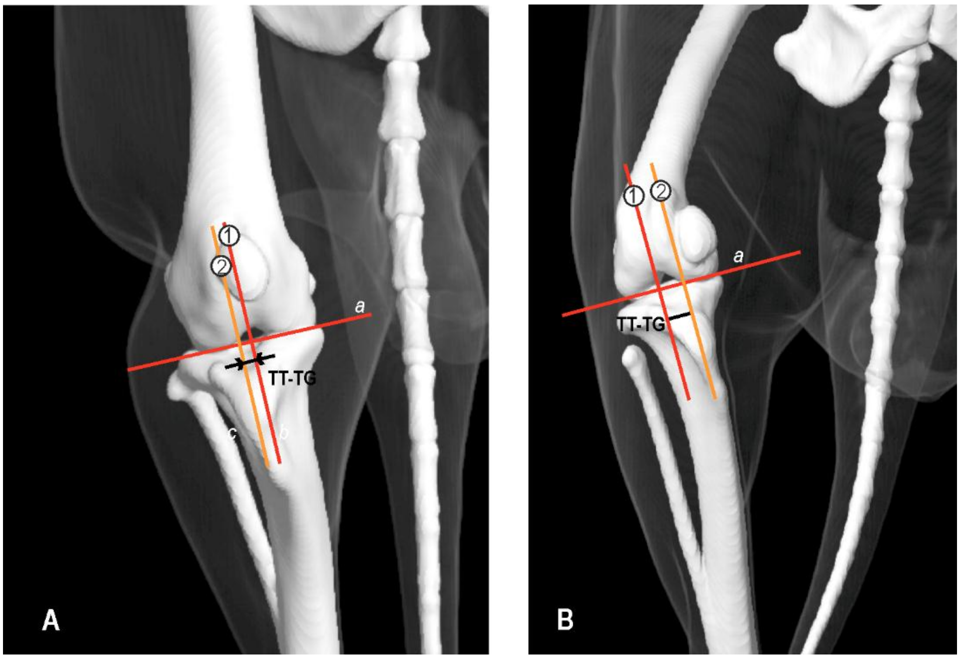

Figure 2 Measurement of the TT-TG distance on 3D reconstructed CT image of a healthy stifle joint (A) and a stifle with grade II medial patellar luxation (B) using the red reference line and the two perpendiculars from trochlear groove bottom (1) and tibial tubercle (2).

Results

The distances between the tibial tuberosity and the trochlear groove measured on 2D and 3D reconstruction images are presented in Table 1. The median TT-TG value (arithmetic mean of both measurements) of healthy stifles was statistically significantly (*P*<0.001) shorter (1.4 mm on 2D and 1.3 mm on 3D reconstruction images) compared to MPL stifles (2.1 mm on 2D and 2.3 mm on 3D reconstruction images).

The conventional 2D CT technique showed good intra-rater ICC of 0.899 (95% CI 0.813–0.947), whereas the 3D-CT technique demonstrated excellent intra-rater ICC: 0.929 with 95% CI from 0.866 to 0.963) (Table 2).

The comparison of both techniques using the Bland-Altman plot (Fig. 3) showed a mean bias of 0.2 mm. All points except for two were within the 95% limits of agreement (-0.94 to 1.34).

Table 1 Results from measurements of TT-TG distance (mm) on 2D and 3D computed tomography scans. Data are presented as median (interquartile range).

Parameter		Healthy group (n=21)	Patellar luxation group (n=15)	P value
2D TT-TG	1st measurement	1.4 (1.3-1.6)	2.1 (1.9-3.5)	
	2nd measurement	1.4 (1.3-1.7)	2.1 (1.9-3.1)	
	Mean of both	1.4 (1.3-1.7)	2.1 (1.9-3.3)	*P*<0.001
3D TT-TG	1st measurement	1.4 (1.2-1.5)	0.23 (1.8-2.8)	
	2nd measurement	1.3 (1.1-1.4)	0.22 (2.0-2.9)	
	Mean of both	1.3 (1.2-1.4)	2.3 (1.8-2.8)	*P*<0.001

Table 2 Intrarater agreement of TT-TG distance measurements in the 36 canine stifles on 2D and 3D computed tomography scans

Parameter	ICC	95% CI
TT-TG on 2D scans	0.899	0.813-0.947
TT-TG on 3D scans	0.929	0.866-0.963

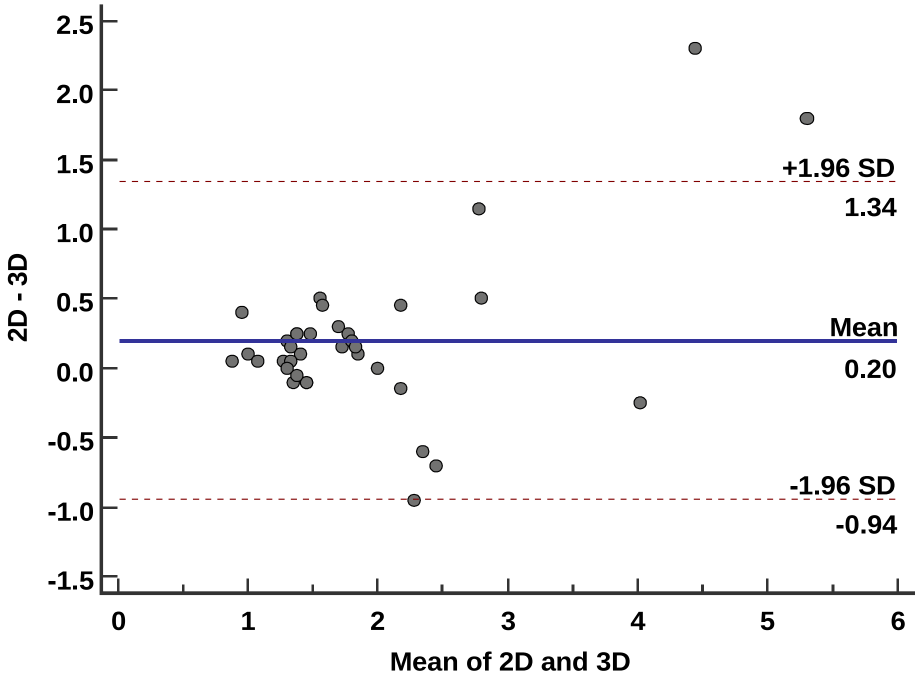

Figure 3 Bland–Altman plot of differences between 2D computed tomography and 3D computed tomography (3D) for healthy and patellar luxation stifles (n=36).

Discussion

This study presents the first data on the tibial tuberosity-trochlear groove distance in small dog breeds and compares the performance of measurements on 2D and 3D reconstruction computed tomography images.

For identification of the posterior condylar line, orthopedists select one from several consecutive CT scans of the region around the medial and lateral femoral epicondyle mainly by intuition. The drawbacks of the classical TT-TG measurement methods of Dejour *et al.* (1994) and Koeter *et al.* (2007) are partly compensated by three-dimensional reconstruction, as the osseous landmarks are better identified on 3D image. While this is easy to be done in healthy animals, patients with angular limb deformities or orthopedic disorders with restricted articular range of motion may present a real challenge. What is more important, the traditional TT-TG determination requires scans in two planes, whereas with 3D reconstruction, only one image is sufficient (Shu *et al.*, 2020). According to presented results in healthy and MPL-affected stifle joints in dogs, the TT-TG values measured on two axial scans through the trochlear groove and the tibial tuberosity and those measured on 3D reconstruction image are entirely compatible. The bias of the two measurement methods was slight, the absolute value of the difference measured by the two methods was at most 0.095 cm indicating that the two methods can be replaced by each other. Our results about the intra-rater agreement were similar to ICC values exceeding 0.95 reported by Miles *et al.* (2013) in red fox stifles.

In a comparative analysis of the strengths and weaknesses of different methods for diagnostic imaging of patellofemoral instability in men, Shu *et al.* (2020) evaluated the concordance between the TT-TG measured by the classical technique (2D) and on three-dimensional (3D) reconstruction images. The obtained intraobserver ICCs were high: 0.852 for 2D and 0.864 for 3D images. The Bland-Altman analysis confirmed that the TT-TG distance measured on 3D images was in good agreement with that measured by the classical technique.

Teo *et al.* (2023) have traced CT scans of 106 knees without patellofemoral pathology on 2D images and 3D models to evaluate intra- and interobserver reliability of each method using intraclass correlation (ICC) and Bland-Altman method. The ICC values of both methods were comparable (95% limits of agreement between the same observer: −3.3 to 3.8 mm versus −2.4 to 2.7 mm). The 3D method resulted in narrower limits of agreement but both TT-TG measurement methods were comparable as the variations were not significant. According to the researchers, the utilisation of the 3D image was easier, faster, more reliable and accurate due to the better visualisation of TT-TG reference bony structures.

The alignment of the tibial tuberosity in relation to the femoral trochlear groove is exceptionally important for the normal functioning of the quadriceps mechanism. The increased tibial torsion alters the pull of the quadriceps muscles and displaces the patella. That is why the determination of the TT-TG distance was judged important for the selection of the surgical correction approach in human patients (Kulkarni *et al.*, 2016). So far, the TT-TG distance was not used in dogs to assess the malalignment of the tibial tuberosity and the femoral trochlear groove. On the basis of data obtained in red fox cadavers, Miles *et al.* (2013) suggested that the definition of normal values of the TT-TG distance in dogs with medial patellar luxation may be useful in the selection of the most biomechanically appropriate surgical technique. The authors hypothesized that dogs with an abnormal TT-TG would require distal realignment to normalize the TT-TG, and additional proximal procedures to neutralize the tendency to luxation.

In our opinion, the preoperative measurement of the TT-TG distance in dogs with medial patellar luxation determination allows for exact determination of the distance for transposition of the tibial tuberosity in direction opposite to patellar luxation for restoration of quadriceps mechanism alignment. The insufficient tibial tuberosity transposition will not restore the normal functions of the quadriceps mechanism whereas the excessive transposition may lead to tibial tuberosity avulsion with subsequent quadriceps muscle contracture. The tibial tuberosity transposition based on the individual deviation of TT-TG from normal will probably result in less post-operative complications.

This preliminary study has several limitations, namely: the low number of measured stifles (both healthy and with MPL), lack of data about inter-rater agreement of the two measurement techniques; lack of data in stifles with higher MPL grades where the identification of osseous landmarks is more challenging. Anyhow, it may be a good basis for future research on canine stifle joint biomechanics.

In conclusion, TT-TG of healthy stifles was statistically significantly ($P<0.001$) shorter on both 2D and 3D images compared to that of grade II MPL stifles. The exact preoperative measurement of the TT-TG distance in dogs with medial patellar luxation determination will allow for a more precise transposition of the tibial tuberosity and restoration of quadriceps mechanism alignment to prevent excessive transposition with possible tibial tuberosity avulsion and subsequent quadriceps contracture – one of the most severe complications of this type of surgery. Measurement of the TT-TG will be useful also in femoral osteotomy surgery in patients with high-grade luxations.

The TT-TG values measured on axial 2D CT scans of the trochlear groove and tibial tuberosity, and those measured on 3D reconstruction images are entirely compatible. The accurate identification of osseous landmarks on 3D reconstruction images allow for easier and faster measurements.

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References

Beitler BG, Yu KE, Wang A, Frumberg DB, Tommasini SM, Wiznia DH, Cooperman DR, Lattanza LL and Fulkerson JP 2023. Three-dimensional printing of the patellofemoral joints of patellar instability patients. Arthrosc Tech. 12: e401-e406.

Benchoufi M, Matzner-Lober E, Molinari N, Jannot AS and Soyer P 2020. Interobserver agreement issues in radiology. Diagn Interv Imaging. 101: 639-641.

Bound N, Zakai D, Butterworth SJ and Pead M 2011. The prevalence of canine patellar luxation in three centres. Clinical features and radiographic evidence of limb deviation. Vet Comp Orthop Traumatol. 1: 32-37.

Campbell CA, Horstman CL, Mason DR and Evans RB 2010. Severity of patellar luxation and frequency of concomitant cranial cruciate ligament rupture in dogs: 162 cases (2004-2007). J Am Vet Med Assoc. 236: 887-891.

Danielsen O, Poulsen TA, Eysturoy NH, Mortensen ES, Hölmich P and Barfod KW 2023. Trochlea dysplasia, increased TT-TG distance and patella alta are risk factors for developing first-time and recurrent patella dislocation: a systematic review. Knee Surg Sports Traumatol Arthrosc. 31: 3806-3846.

Dejour H, Walch G, Nove-Josserand L and Guier C 1994. Factors of patellar instability: an anatomic radiographic study. Knee Surg Sports Traumatol Arthrosc. 2: 19-26.

Goutallier D, Bernageau J and Lecudonnec B 1978. Mesure de l'écart tubérosité tibiale antérieure - gorge de la trochlée (T.A.-G.T.). Technique. Résultats. Intérêt. Rev Chir Orthop Reparatrice Appar Mot. 64: 423-428.

Hulse DA 1995. The stifle joint. In: Small Animal Orthopedics. 1st ed. ML Olmestead (ed). St. Louis: Mosby. 395-403.

Koeter S, Pakvis D and van Loon CJ 2007. Trochlear osteotomy from patellar instability: satisfactory minimum 2-year results in patients with dysplasia of the trochlea. Knee Surg Sports Traumatol Arthrosc. 15: 228-232.

Kulkarni S, Shetty AP, Alva KK, Talekar S and Shetty VD 2016. Patellar instability in Indian population: relevance of tibial tuberosity and trochlear groove distance. SICOT J. 2:4.

Lee J, Sim H, Jeong J, Kim SY, Yang S, Jeong S and Lee H 2020. Biomechanical analysis of canine medial patellar luxation with femoral varus deformity using a computer model. BMC Vet Res. 16: 471.

Lusetti F, Bonardi A, Eid C, De Bellesini AB and Martini FM 2017. Pelvic limb alignment measured by computed tomography in purebred English Bulldogs with medial patellar luxation. Vet Comp Orthop Traumatol. 30: 200-208.

Miles JE, Jensen BR, Kirpensteijn J, Svalastoga EL and Eriksen T 2013. Measurement repeatability of tibial tuberosity-trochlear groove offset distance in red fox (Vulpes vulpes) cadavers. Am J Vet Res. 74: 888-894.

Nha K, Nam YJ, Shin MJ, Sun SD, Park JY, Debnath R and Lee BH 2019. Referencing the trochlear groove based on three-dimensional computed tomography imaging improves the reliability of the measurement of the tibial tuberosity-trochlear groove distance in patients with higher grades of trochlea dysplasia. Knee. 26: 1429-1436.

Okamoto S, Mizuuchi H, Okazaki K, Hamai S, Tashiro Y, Nakahara H and Iwamoto Y 2016. Two-dimensional planning can result in internal rotation of the femoral component in total knee arthroplasty. Knee Surg Sports Traumatol Arthrosc. 24: 229-235.

Shu L, Ni Q, Yang X, Chen B, Wang H and Chen L 2020. Comparative study of the tibial tubercle-trochlear groove distance measured in two ways and tibial tubercle-posterior cruciate ligament distance in patients with patellofemoral instability. J Orthop Surg Res. 15: 209.

Swiderski JK and Palmer RH 2007. Long-term outcome of distal femoral osteotomy for treatment of combined distal femoral varus and medial patellar luxation: 12 cases (1999-2004). J Am Vet Med Assoc. 231:1070-1075.

Teo SH, Ong TK, Merican AM, Hashim MS, Ng WM, Al-Fayyadh MZM and Ali MRM 2023. Are two- and three-dimensional computed tomographic scan measurements of tibial tubercle–trochlear groove distance equivalent? A comparative study. Indian J Orthop. 57: 847-855.

Yasukawa S, Edamura K, Tanegashima K, Seki M, Teshima K, Asano K, Nakayama T and Hayashi K 2016. Evaluation of bone deformities of the femur, tibia, and patella in Toy Poodles with medial patellar luxation using computed tomography. Vet Comp Orthop Traumatol. 29: 29-38.