Accuracy of an automated three-dimensional technique for the computation of femoral angles in dogs

Longo, Federico ; Savio, Gianpaolo ; Contiero, Barbara ; Meneghello, Roberto ; Concheri, Gianmaria ; Franchini, Federico ; Isola, Maurizio

Abstract: Aims: The purpose of the study was to evaluate the accuracy of a three-dimensional (3D) automated technique (computer-aided design (aCAD)) for the measurement of three canine femoral angles: anatomical lateral distal femoral angle (aLDFA), femoral neck angle (FNA) and femoral torsion angle.Methods:Twenty-eight femurs equally divided intotwo groups (normal and abnormal) were obtained from 14 dogs of different conformations (dolicomorphic and chondrodystrophicCT scans and 3D scanner acquisitions were used to create stereolithographic (STL) files , which were run in a CAD platform. Two blinded observers separately performed the measurements using the STL obtained from CT scans (CT aCAD) and 3D scanner (3D aCAD), which was considered the gold standard method. C orrelation coefficients were used to investigate the strength of the relationship between the two measurements.Results: A ccuracy of the aCAD computation was good, being always above the threshold of R<jats:sup>2</jats:sup> of greater than 80 per cent for all three angles assessed in both groups. a LDFA and FNA were the most accurate angles (accuracy gt;90 per cent).Conclusions: The proposed 3D aCAD protocol can be considered a reliable technique to assess femoral angle measurements in canine femur. The developed algorithm automatically calculates the femoral angles in 3D, thus considering the subjective intrinsic femur morphology. The main benefit relies on a fast user-independent computation, which avoids user-related measurement variability. The accuracy of 3D details may be helpful for patellar luxation and femoral bone deformity correction, as well as for the design of patient- specific, custom-made hip prosthesis implants.

DOI: https://doi.org/10.1136/vr.105326

Originally published at:
Longo, Federico; Savio, Gianpaolo; Contiero, Barbara; Meneghello, Roberto; Concheri, Gianmaria; Franchini, Federico; Isola, Maurizio (2019). Accuracy of an automated three-dimensional technique for the computation of femoral angles in dogs. Veterinary Record, 185(14):443.
DOI: https://doi.org/10.1136/vr.105326

Research article

Accuracy of an automated three-dimensional technique for the computation of femoral angles in dogs

F. Longo [a, d] *, G. Savio [b], B. Contiero [a], R. Meneghello [c], G. Concheri [b], F. Franchini[b], M. Isola [a]

[a] *Department of Animal Medicine, Production and Health, University of Veterinary Medicine, Padova, Italy*
[b] *Laboratory of Design Tools and Methods in Industrial Engineering, Department of Civil, Architectural and Environmental Engineering, University of Engineering, Padova, Italy*
[c] *Department of Management and Engineering, University of Padova, Vicenza, Italy*
[d] *Clinic for Small Animal Surgery, Vetsuisse Faculty University of Zurich, Zurich, Switzerland*

* Corresponding author. Tel: +39 049 8272608.
E-mail address: flongo@vetclinics.uzh.ch (F. Longo).

Abstract

The purpose of the study was the evaluation of the accuracy of a three-dimensional (3D) automated technique (aCAD) for the measurement of three canine femoral angles: anatomical lateral distal femoral angle (aLDFA); femoral neck angle (FNA); and femoral torsion angle (FTA).

Twenty-eight femurs equally divided in 2 groups (normal and abnormal) were obtained from 14 dogs of different conformations (dolicomorphic and chondrodystrophic).

Computed tomographic (CT)-scans and 3D scanner acquisitions were used to create stereolithographic (STL) files which were run in a computer-aided-design (CAD) platform. Two blinded observers performed separately the measurements using the STL obtained from CT-scans (CT aCAD) and 3D scanner (3D aCAD), which was considered the gold standard method.

The correlation coefficients were used to investigate the strength of the relationship between the two measurements.

The accuracy for the aCAD computation was good, being always above the threshold of R^2> 80% for all three angles assessed in both groups. ALDFA and FNA were most accurate angles (accuracy > 90 %).

The proposed 3D aCAD protocol can be considered a reliable technique to assess femoral angle measurements in the canine femur. The developed algorithm automatically calculates the femoral angles in 3D, thus considering the subjective intrinsic femur morphology. The main benefit relies on a fast user-independent computation, which avoid user-related measurement variability. The accuracy of 3D details may be helpful for patellar luxation and femoral bone deformity correction as well as for the design of patient specific custom-made hip prosthesis implants.

Keywords: Accuracy, Dog; Femur; Computed tomography; Three-dimensional constructions; 3D scanner

Introduction

The state of art for the measurement of angles in the canine femur has been traditionally limited to multiple orthogonal radiographs (RX),[1-3] which were gradually overtaken by the computed tomography (CT)-scans [4,5] and magnetic resonance (MRI) evaluations. [6,7] These latter two diagnostic techniques exhibit satisfactory aptitudes in terms of bone and images manipulation, avoiding the positioning issue that frequently characterizes the radiographic evaluation.[4,8] However, CT and MRI lack on real three-dimensional (3D) measurement of angles since that almost for all the values proposed by the literature were achieved with two-dimensional (2D) imaging. [6,9,10] Recently a 3D Python-based algorithm run on a computer-aided-design (CAD) software (Rhinoceros version 5, Robert McNeell & Associates) was presented as a novel methodology for the computation of femoral angles in the canine femur.[11,12] The femoral angles computed, differently from those obtained using different diagnostic techniques, [1-10] were measured in a real 3D fashion. The main benefit relies on automated measurements, which are independent from the points selected by the operator, bone orientation and conformation as well. As a result, the operator-related measurement variability is decreased as the manual manipulation of the bone model and the identification of target anatomical landmarks are not required. The repeatability and reproducibility of the proposed protocol were assessed and compared with manual measurements made with radiographs and CT reconstructions, finding that the 3D protocol was the most repeatable and reproducible method.[12] This conclusion was, also, supported by the automated design of the 3D protocol, which restricts the potential user-related errors only to the operations required for the creation of the mesh model and, therefore, remarkably decreases the computational time.[11] However, the accuracy of 3D measurements, described as the difference of a measured value from a true value, was not assessed and needed to be investigated. Therefore, the purpose of this study was to determine the accuracy of our aCAD protocol for the computation of three femoral angles in dogs: anatomical lateral distal femoral angle (aLDFA); femoral neck angle (FNA); and femoral torsion angle (FTA).

Polygonal mesh models were created from 3D reconstructions of CT images and femoral angles were computed with the developed protocol. The values obtained were compared to the measurements performed with the same aCAD protocol but executed on polygonal mesh models generated by 3D scans, which due to its high-resolution 3D nature, was assumed as the gold standard technique for this study.

The second object of this study was to assess the efficacy of the aCAD protocol for the measurement of femoral angles in either normal or abnormal femurs.

Materials & Methods

Fourteen canine paired pelvic limbs were collected. The cadavers were euthanized for reasons unrelated with this project and a signed informed consent was requested before proceeding with imaging acquisition and femur disarticulation. The study was conducted in a double-blind fashion by two observers (an orthopaedic surgeon and an engineer). Moreover, one experienced radiologist acquired all radiographic and CT images. He, also, anonymised all CT scans using a legend and separately packed every femur sample to prevent any conditioning for the observers.

Specimens were first radiographed with digital radiographic equipment (Kodak Point of Care CR-360 System, Carestream Health). A standard ventro-dorsal and latero-lateral views were performed.

CT scans

CT scans were then acquired with four multi-detector row CT scanner (Toshiba Asteion S4, Toshiba Medical Systems Europe). Dogs were positioned with a supine recumbence with legs adducted, extended and tied above the stifles. An amperage of 150 mA, exposure time of 0.725 s and voltage of 120 kV were set on. A slice thickness of 1 mm (reconstruction interval 0.8 mm) was applied. CT images were reconstructed with a high-resolution filter for bones with the following bone window (window length 1000 Hounsfield units, HU; window width 4000 HU). A 3D volume reconstruction was done using a DICOM-processing software (Osirix version 2.7, pixmeo SARL). The first observer isolated with Osirix every anonymized femur by cropping the tibia and pelvis, avoiding unintentional modification of the profiles of the femoral head and condyles. Once the femur model was separated, it was segmented using the procedure described by Longo et al.[12] Briefly, using the region of interest (ROI) and 2D/3D growing region software functions, the observer found the mean density femur values, which usually are major than 300 Hounsfield unit (HU) and then set-up the segmentation parameters in a dedicated tool window. As a result, a bitmapped (newly generated imaging series) was created and 3D reconstructed, through surface rendering function. Finally, a 3D stereolithograophic (STL)[13] file was saved and imported in the Rhinoceros platform.[11,12]

3D scans

STL files were generated from 3D scans to obtain reference models on which compare femoral angles measured on CT. Femurs were disarticulated at coxo-femoral and femoral-tibial joints, dissected free from soft tissues excluding the patella and fabellae and stored in plastic bags at a -20°. A 3D scanner (Cronos 3D dual, Open technologies) was used for the femoral analysis. The second observer positioned every anonymised femur on a circular rotating platform. The scanning of the femur was performed adopting a triangulation technique, based on cameras, characterized by a predetermined convergence angle and a fringe projector. The platform was automatically rotated of a predetermined angle sequence, obtaining at least 5 to 10 acquisitions. A 3D geometrical bone model was generated superimposing and aligning the multiple views of the model, obtained per each sequence, by means of an engineering software (Optical RevEng, Open technologies). Cleaning, filtering and closing-holes phases were used to delete model inaccuracies such as noises and local spikes. As a result, a high-resolution mesh model of the bone was obtained and saved as a STL file. The accuracy of the 3D scanner is ±30 µm.[14] Similar results were obtained by the internal verification procedure based on ISO (10360-8:2013) at the Laboratory of Design Tools and Methods in Industrial Engineering. Considering that the 3D scanner accuracy is higher more than an order of magnitude compared to CT axial resolution (0.8 mm), it is possible to assume the 3D scan models as reference.

Automated-CAD measurements from CT reconstructions (CT aCAD) and 3D scanner (3D aCAD)

Both observers imported each CT (Fig. 1) or 3D (Fig. 2) STL file in the CAD software where the aCAD protocol was used to measure femoral angles. The aCAD computation was performed following the same procedure steps described by Savio et al.[11] In brief, the vertices inside the femoral medullary canal (internal mesh) were selected and deleted. This operation is needed to improve the quality of axis drawing and angle measurements, as the presence of internal vertices may interfere with the automatic computation. Then, the femoral analysis was initiated by clicking on the femoral head. To compute the femoral angles, the developed algorithm first identifies points, planes and axis into the femur mesh. It performed all the measurements in few minutes through four automatic phases: 1) femur alignment; 2) proximal femoral long axis computation; 3) analysis of the proximal femoral epiphysis; 4) analysis of the distal femoral epiphysis. During these two final phases, the vertices representing the femoral head and condyles were superimposed by spheres (Fig. 1 and 2).[11,12] Finally, aLDFA, FNA and FTA angles were displayed on the screen and recorded by the observer.

Groups

Considering radiographic, CT and visual gross evaluation, the specimens were examined for evidence of osteoarthritis (OA) and difference of breed conformation (dolicomorphic vs chondrodystrophic). The femurs were divided in two groups. Group 1 was assigned as normal, adopting the following inclusion criteria: femurs were obtained from dolicomorphic breeds with no evidence of OA. Whereas the second category was more heterogenic and included femurs either affected by OA regardless of conformation or taken from chondrodrystophic breeds (Fig. 3).

The radiologist radiographically evaluated the degree of OA and converted the OA score to a numeric scale (0= none; 1= mild; 2= moderate ;3= severe).[15,16]

Statistical analysis

The statistical analyses were performed using a commercially available software (SAS 9.4, SAS Institute Inc., Cary, NC, USA). Normality distribution hypothesis was assessed by Shapiro-Wilk test. A linear regression analysis was applied, considering the gold standard method (3D aCAD) as the independent variable and the CT aCAD as the dependent variable.

The adjusted R^2 was used to quantify the strength of the relationship between the angle measured through CT aCAD (observer 1) and 3D aCAD (observer 2) techniques. Adjusted R^2 values > 80 % were considered acceptable. The hypotheses of the linear model on the residuals were graphically assessed.

The descriptive statistics (means, standard deviations, medians and interquartile ranges) were calculated for each angle (aLDFA, FNA and FTA) measurements for both imaging techniques.

The paired Student t-test was performed to compare the data recorded with CT aCAD and the gold standard. Statistical significance of P-value was set at < 0.05.

Results

Twenty-eight femurs divided in two groups (1 = normal, 2= abnormal) of 14 femurs each, were used for this study. The specimens were obtained from dogs of different breeds and conformations: 3 mixbreed dogs, 2 Dachshunds, 2 French bouledogs and 1 Pug, German shepherd, Labrador R., Bernese mountain dog, Segugio italiano, Amstaff and Great Dane. Ten dogs were intact males, 3 were spayed females and 1 was a not-spayed female. The overall mean body weight was 19.5 kg (range 4-44 kg), whereas the body weight means of the groups were: group 1 (16.1 kg, range 13-28 kg) group 2 (19.3 kg, range 4-44 kg). The overall mean age was 9.5 years (range 2-15 years). The mean age of group 1 was 4.7 years (range 2-8 years), while group 2 had a mean age of 12.5 years (range 9-15 years).

Group 1 included 14 dolicomorphic femurs with no evidence of radiographic OA. Within the 14 femurs of the group 2, there were: 4 chondrodystrophic femurs not affected by OA, 6 chondrodystrophic femurs affected by OA (mean OA score: 1) and 4 dolicomorphic femurs affected by OA (mean OA score: 2).

All data regarding the 3 angles and for both CT aCAD and 3D aCAD measurements were normally distributed (Shapiro-Wilk test >0.9). The values of the angles recorded were well aligned along regression lines in almost all the samples, excepted for some femurs included in group 2 (Fig. 4) The adjusted R^2 value of the CT aCAD and 3D aCAD measurements resulted always above the acceptance criterion of 80%, regardless of the angle measured and the group considered. Overall, the coefficients calculated for all 28 femurs were: aLDFA > 95%; FNA > 95% and FTA > 86% (Fig. 4). Specifically, within group 1 the coefficients were: aLDFA > 93%; FNA > 93% and FTA >

98%, while within group 2: aLDFA > 97%; FNA > 94% and FTA > 82% (Fig. 4). Technique-related means, medians and interquartile ranges values for the 3 angles are displayed in Table 1. The t-test showed that there was not a statistically significant difference ($P < 0.05$) in the mean difference values of each paired measurements for every angle assessed, excepted for FTA measurement in group 2 (Table 2)

Discussion

This study investigated the accuracy of a novel automated 3D technique (aCAD) for the computation of canine femoral angles. We used the correlation coefficients to assess the strength of the relationship between the angle measurements performed by the observers in Rhino starting from STL files created either from CT-scans (CT aCAD) or 3D scanner (3D aCAD). The aCAD methodology has, looking at the accuracy investigation, been satisfactory for all three angles assessed (> 82%).

This suggests that the CT aCAD measurements were comparable to the 3D aCAD measurements, which represented our reference standard method of assessment. The practical consequence is that the developed 3D protocol is not only repeatable and reproducible[12] but also may be considered enough accurate. However, a validation of the 3D scanner on bone measurements needs to be performed to corroborate this subjective assumption.

The accuracy of a test is a description of how close a measured value is to an assumed true value; which means that a “true” value must be both identifiable and measurable, thus providing an unequivocal gold standard against which new tests may be assessed.[4,16] In this study, we have assumed 3D scanner measurements of femoral anatomic specimens as the gold standard method for two main reasons. First, 3D scanner allows for creating detailed and precise geometrical bony models[17] that could nicely reproduce the original femoral morphology. We have applied white spray onto the femoral specimens and waited at least 24 hours before the image acquisition with the scanner. The aim was to increase the visualization of the femoral cortices, decreasing the radiotransparency of the bone and thus improve the quality of the femoral captures. Second, 3D scanner allows the user to work with real 3D files, which we cannot obtain from other reported two-dimensional techniques. [9,18] It may be argued that we could have either measured the femoral angles on digital photography images of femur specimens or calculated them directly onto the bones. Although, the quantification of an established "true" value for a such variable measurement (angle) depends on arbitrary anatomic landmarks, in the authors' opinion a comparison between a 3D technique (aCAD) with a 2D gold standard method (digital photography) wouldn't be feasible. The reason is attributable to the structured differences of the methodologies tested.

A direct measurement of femoral angles onto femurs specimens could have represented an alternative gold standard. However, we believe that such method couldn't represent an accurate methodology as well because precise anatomic reference lines needed to be drawn, increasing the risk of operator-measurement errors.

Overall, the aLDFA and FNA were the most accurate angles since that their correlation coefficients were always above the 90% threshold, regardless of the groups considered. FTA measurements were still satisfactory but showed a lesser accuracy. These results partially confirmed the data that we previously presented.[12] Specifically, the aLDFA represents the most repeatable, reproducible and accurate angle to measure. The FNA, which resulted as the lesser repeatable and reproducible angle to be quantified with three different diagnostic techniques (RX, CT and aCAD computation), here exhibited comparable values between CT aCAD and 3D aCAD. Whereas, the measurements recorded for the FTA resulted as the most out of range from the real values, but still within the established threshold of acceptance (> 80%) in both normal and abnormal femurs.

The computation ability of the developed protocol in femurs of different dimensions, conformations (dolicomorphic and chondrodystrophic breeds) as well as in femurs affected or unaffected by OA, represented a key point of our project. Previously, the described 3D protocol was performed mrely on normal femurs, free of orthopaedic diseases.[11,12]

The femoral angles measured by the observers are commonly quantified in the preoperative planning of patellar luxation ,[5,19] which is frequently caused by femoral deformities.[20,21] These skeletal malformations cause imbalanced joint loading and when they are either severe or lately diagnosed (chronic), they may lead to OA which deforms the articular profiles.[22-24] In this study, 10 out of 28 femurs were affected by OA, of which one (femur 19) had a severely arthritic femoral head (OA score: 3) (Fig. 5) and two (femurs 25 and 26) had the condylar profiles altered (OA score: 2). The massive remodeling of the articular profiles, above all of the femoral head, represents both a challenge for the computational analysis and a plausible explanation for a less than perfect accuracy detected for the FTA. The algorithm needs to correctly identify and fit the original sphere of the femoral head and condyles. During the pilot developing phase, the algorithm was set up to exclude from the analysis all the vertices that belong to external components of the femoral head fitting such as osteophytes, which could potentially alter the computational analysis.[11] The FTA correlation coefficient obtained for the computation of abnormal femurs (R^2=82%) means that the algorithm effectively analyses also deformed femoral heads but not as accurately as for FNA and aLDFA computation ($\geq$ 92%). Considering the satisfactory FTA accuracy in the normal group (R^2 FTA > 98%), we attribute the lower FTA accuracy in abnormal femurs mainly to the difficulty of analysing severely altered femoral head profiles. However, the accuracy obtained was still major than 80% threshold (R^2=82%).

The descriptive statistic displayed in Table 1 shows that the values measured for FNA and FTA fall within the ranges described in the literature: FNA (125°-138°) [3,25] and FTA (12-40°). [2, 25]

The FNA and especially FTA reference ranges are wide.[2,3,25] In the authors' opinion this is concerning and need to be clarified as femoral torsion is frequently detected in case of patellar luxation and need to be often corrected. The accepted clinical tolerance for FTA suggests that there is a variable either depending on the femur morphology or on the observer ability which influences the angle measurements. Explanations may rely on the identification of the target points such as the center of the femoral head and neck, which could be challenging for the observer, especially in the case of severe OA. Our FTA mean ranges from 20-22° (table 1), which agrees with our previous results[11,12] and with the literature ranges.[2,25] However, sometimes a 27° reference value for femoral torsional deformity is assumed,[20] and therefore the obtained FTA mean implies that our 3D technique identifies a more retroverted position of the femoral head. Whether this result may have a clinical impact could not be answered with this study and therefore need to be further investigated. The aLDFA mean values, accordingly with those already found by the authors' [11,12] are slightly lower than the reported range (aLDFA 94-98°).[3, 25] We impute this result mainly to morphologic heterogeneity of the femurs computed. We analyzed a range of femurs of different dimensions (small to large dogs) and conformations (dolicomorphic and chondrodystrophic), while the data reported in literature were obtain mainly in large dolicomorphic dogs.[16,25] It is plausible to expect that chondrodystrophic dogs as well as small size breeds may be characterized by different values regarding frontal and torsional femoral alignment. Furthermore, the t-test analysis exhibited a not significant difference for each paired of values assessed. In almost for all the cases evaluated, the CT aCAD measurements tended towards underestimating the femoral angle values compared to the gold standard, but this tendency was statistically significant only for the femoral torsion evaluation in the group of abnormal femurs (Table 2).

Conclusions

We have shown that the automatic measurements obtained from CT derived data are significantly comparable with high-resolution 3D scanner-derived data, suggesting that the tested automated CAD technique is an accurate methodology for measuring femoral angles in both normal and abnormal canine femurs. However, currently it is not validated what should a gold standard be for 3D measurements. Therefore, further studies could be undertaken to compare anatomical versus 3D scanner measurements of bones.

The presented methodology could represent a reliable diagnostic method to adopt when a femoral deformity is suspected, having the automated and 3D nature of its assessments and rapidity of its computational analysis as main substantial benefits. Moreover, the precision of patellar luxation planning may increase, due to the user-independent structure of measurements. Finally, the possibility to correctly identify anatomic landmarks such as the original curvature of the femoral head, the external and internal profiles of the femoral neck, and potentially the original morphology of the acetabulum, even in the case of a severe degenerative joint disease, may extends its usefulness in the future, also, for arthroplasty purposes. However, further evaluations need to be done with a greater number of samples to improve the quality and the precision of the femur computation in severely arthritic femoral heads.

Conflict of interest statement

None of the authors of this paper have a financial or personal relationship with other people or organisations that could inappropriately influence or bias the content of the paper.

References

1. Bardet JF, Rudy RL, Hohn RB. Measurement of femoral torsion in dogs using a biplanar method. Vet Surg 1983;12:1-6.

2. Montavon, P.M., Hohn, R.B., Olmestead, M.L., Rudy, R.L., 1985. Inclination and anteversion angles of the femoral head and neck in the dog evaluation of a standard method of measurement. Vet Surg 1985;14:272-282.

3. Tomlison, J, Fox D, Cook JL, *et al*. Measurement of femoral angles in four dog breeds. Vet Surg 2007;36:593-598.

4. Oxley B, Gemmill TJ, Pink J, *et al*. Precision of a novel computed tomographic method for quantification of femoral varus in dogs and an assessment of the effect of femoral malpositioning. Vet Surg 2013;42:751-758.

5. Barnes, D.M., Anderson, A.A., Frost, et al. Repeatability and reproducibility of measurements of femoral and tibial alignment using computed tomography multiplanar reconstructions. Vet Surg 2015;44:85-93.

6. Kaiser S, Cornely D, Golder W, *et al.* The correlation of canine patellar luxation and the anteversion angle as measured using magnetic resonance images. Vet Radiol Ultrasound 2001;42:113-118.

hat formatiert: Deutsch (Schweiz)

7. Ginja MMD, Ferreira, AJA, Jesus SS, *et al.* Comparison of clinical, radiographic, computed tomographic, and magnetic resonance imaging methods for early prediction of canine hip laxity and dysplasia. Veterinary Radiol Ultrasound 2009;50:135-143.

8. Jackson GM, Wendelburg KL. Evaluation of the effect of distal femoral elevation on radiographic measurement of the anatomic lateral distal femoral angle. Vet Surg 2012;41:994-1001.

9. Dudley RM, Kowaleski MP, Drost, WT, *et al*. Radiographic and computed tomographic determination of femoral varus and torsion in the dog. Veterinary Radiol Ultrasound 2006;47:546-552.

10. Yasukawa S, Edamura K, Tanegashima K, *et al.* Evaluation of bone deformities of the femur, tibia, and patella in Toy Poodles with medial patellar luxation using computed tomography. Vet Comp Orthop Tramatol 2016;29:29-38.

11. Savio G, Baroni T, Concheri G, *et al.* Computation of femoral canine morphometric parameters in three-dimensional geometrical models. Vet Surg 2016;45:987-995.

12. Longo, F., Nicetto, T., Banzato T, *et al.* Automated computation of femoral angles in dogs from three-dimensional computed tomography reconstructions: Comparison with manual techniques. Vet J 2018;232:6–12.

13. Botsch M, Kobbelt L, Pauly M, *et al*. Mesh data structures. In: Botsch ed. Polygon Mesh Processing, 1st Edn. MA, USA: A.K. Peters, 2010 pp. 21-28

14. https://www.growshapes.com/store/p137/Open-Technologies-3D-Scanner/Cronos-3D-Dual-3MP.html. Last access 12/04/2019.

15. Lopez MJ, Lewis BP, Swaab ME, *et al*. Relationships among measurements obtained by use of computed tomography and radiography and scores of cartilage microdamage in hip joints with moderate to severe joint laxity of adult dogs. Am J Vet Res 2008;69:362-370.

16. D'Amico LL, Xie L, Abell LK *et al*. Relationships of hip joint volume ratios with degrees of joint laxity and degenerative disease from youth to maturity in a canine population predisposed to hip joint osteoarthritis. Am J Vet Res 2011;72:376-383.

17. Palmer RH, Ikuta CL, Cadmus JM 2011. Comparison of femoral angulation measurement between radiographs and anatomic specimens across a broad range of varus conformations. Vet Surg 2011;40:1023-1028.

18. Fahrni S, Campana L, Dominguez A, *et al.* CT-scan vs. 3D surface scanning of a skull: first considerations regarding reproducibility issues. Forensic Sciences Research 2017;2:99-99.

19. Swiderski JF, Radecki SV, Park RD, *et al.* Comparison of radiographic and anatomic femoral varus angle measurements in normal dogs. *Vet* Surg 2008;37:43-48.

20. Gibbons SE, Macias C, Tonzing MA, *et al*. Patellar luxation in 70 large breed dogs. J Small Anim Pract 2006; 47: 3–9.

hat formatiert: Deutsch (Schweiz)

hat formatiert: Deutsch (Schweiz)

hat formatiert: Deutsch (Schweiz)

hat formatiert: Deutsch (Schweiz)

21. Brower BE, Kowaleski MP, Peruski AM, *et al*. Distal femoral lateral closing wedge osteotomy as a component of comprehensive treatment of medial patellar luxation and distal femoral varus in dogs. Vet Comp Orthop Tramatol 2017;20-27.

22. Roch SP, Gemmill TJ. 2008. Treatment of medial patellar luxation by femoral closing wedge ostectomy using a distal femoral plate in four dogs. J Small Anim Pract 2008;249:52–158.

23. Dobbe J, du Pre` KJ, Kloen P, *et al*. Computer-assisted and patient-specific 3-D planning and evaluation of a single-cut rotational osteotomy for complex long-bone deformity. Medical & Biological Engennering & Computing 2011;49:1363–1370.

24. Milner SA, Davis TR, Muir KR, *et al*. Long-term outcome after tibial shaft fracture: is malunion important? Journal of Bone and Joint Surgery American volume 2002; 84A:971–980.

25. Petazzoni, M. Radiographic measurements of the femur. In: Petazzoni, M., Jaeger, G.H. (Eds). Atlas of Clinical Goniometry and Radiographic Measurements of the Canine Pelvic Limb. 2nd Edn. Merial, Milano, Italy: Merial, 2008, pp. 34-54.

hat formatiert: Deutsch (Schweiz)

hat formatiert: Deutsch (Schweiz)

hat formatiert: Deutsch (Schweiz)

Table 1 descriptive statistics measured with both computed tomography (CT aCAD: tested protocol) and 3D scanner (3D aCAD: gold standard) techniques for each angle.

Technique		aLDFA	FNA	FTA
CT aCAD	Mean ± SD	92.51 ± 5.4	125.32 ± 10.2	21.96 ± 7.1
	Median	92.7	127.96	21.58
	IQR	7.7	8.28	8.8
3D aCAD	Mean ± SD	92.55 ± 5.3	124.26 ± 10.8	20.87 ± 6.4
	Median	92.2	126.8	20.2
	IQR	6.95	11.85	6.25

Table 2 Mean difference and P-value of paired t-test calculated for each angle.

T- test		aLDFA		FNA		FTA	
		Normal	Abnormal	Normal	Abnormal	Normal	Abnormal
	Mean	- 0,14°	0,22°	- 0.24	- 0.24	- 0.41	- 1.77

Mean Difference	± SD	± 1,16	± 0,79	± 0.82	± 3.82	± 0.79	± 3.21
	P-value	0,65	0,3	0,29	0,08	0,07	0,05

Figure legends

Fig. 1. 3D computation performed in a stereolithographic file obtained from a computed tomography reconstruction (CT aCAD) of a 2-years-old French Bouledog. After the 3D computation, femoral axes appear in the bone model (A). The green line is the femoral head and neck axis (FHNA), the blue lines represent the mechanical axis (MA) and the hip joint orientation line (HJOL), the red line is the proximal femoral long axis (PFLA) and the gold line is the transcondylar axis (TCA). (B) Cranial and caudal aspect of the proximal femoral epiphysis. Notice the fitting of the femoral head and the section of the femoral neck (light blue). (C) Medial-lateral

and caudal-cranial views of the femoral condyles. Note the sphere fitting of both condyles (light blue spheres) as well as the green vertices that represent the contact area of the TCA.

Fig. 2. 3D computation performed in a stereolithographic file obtained from a 3D-scanner acquisition (3D aCAD) of a 4-years-old Bernese mountain dog (A). The green line is the femoral head and neck axis (FHNA), the blue lines represent the mechanical axis (MA) and the hip joint orientation line (HJOL), the red line is the proximal femoral long axis (PFLA) and the gold line is the transcondylar axis (TCA). (B) Cranial and caudal aspect of the proximal femoral epiphysis. Notice the presence of red vertices outside of the femoral head fitting which represent parts of the acetabulum excluded from the computation. (C) Medio-lateral and caudal-cranial aspects of the distal femoral epiphysis. TCA, PFLA and MA are visible.

Fig. 3. Cranio-caudal views of four abnormal femurs after importation on Rhinoceros. (A) Right femur of a 12-years-old German Shepherd severely affected by osteoarthritis (OA) of the femoral head. (B) Right femur of a 10-years-old Pug which had a severe degeneration of the femoral head and neck. (C and D) Left chondrodystrophic femurs affected by mild (C) and severe OA (D) of the distal femoral epiphysis. The dogs were an 8-years-old French Bouledog and a 13 years-old Dachshund.

Fig. 4. Graphical representation of the regression analysis. Line (A): regression line of the totality of the femurs assessed for each angle. The R^2 are >80 % for all three angles. Line (B): regression analysis of group 1 (normal femurs). The R^2 are > 93 %, having the FTA measurement as the most accurate angle. Line (C): graphical representation of the regression of group 2 (abnormal). The aLDFA angle was the most accurate (R^2> 93 %), while the FTA the most challenging to measure (R^2> 82 %).

Fig. 5. Digital cranio-caudal photograph of the femur specimen of a 12-years-old German Shepherd. (B and C) Cranial and caudal views of the femoral head and neck. The green line is the femoral head and neck axis (FHNA), the blue lines represent the mechanical axis (MA) and the hip joint orientation line (HJOL), the red line is the proximal femoral long axis (PFLA). Observe that the osteophytes fall outside the green sphere and are not considered for fitting of the femoral head. (D) Caudal view of the femoral condyles: the MA and transcondlyar axis (gold line) are drawn. (E) Femoral cranio-caudal view after the 3D computation.