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Measurement of the femoral neck anteversion angle in the dog using computed tomography

M.M.D. Ginja [a,*], J.M. Gonzalo-Orden [b], S.S. Jesus [c], A.M. Silvestre [d], M.P. Llorens-Pena [e], A.J.A. Ferreira [c]

[a] *Department of Veterinary Science-CETAV, University of Trás-os-Montes e Alto Douro, 5000-801 Vila Real, Portugal*
[b] *Department of Animal Pathology, Animal Medicine, Veterinary Faculty, University of Léon 24071, Spain*
[c] *Department of Clinic-CIISA, Faculty of Veterinary Medicine, Technical University of Lisbon 1300-477, Portugal*
[d] *Department of Zootechny-CECAV, University of Trás-os-Montes e Alto Douro, 5000-801 Vila Real, Portugal*
[e] *Department of Animal Medicine and Surgery, Veterinary Faculty, University Complutense, 28040 Madrid, Spain*

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Abstract

Simple and accurate limb and pelvic conformation evaluation using computed tomography (CT) can be useful in planning canine hip dysplasia (CHD) treatment and in helping to understand the pathogenesis of osteoarthritis and CHD. The objectives of this study were to describe a new method for femoral neck anteversion angle (FNA-angle) measurement in CT, and to compare it to the established radiographic standard biplanar method. The hips of 23 Estrela Mountain Dogs were evaluated using radiography and CT and their FNA-angles were determined by performing two CT examinations and with one radiographic measurement session. The intra-class correlation coefficient (ICC) was used to evaluate the repeatability (agreement between the two CT sessions, ICC = 0.92) and reproducibility (agreement between each CT and radiographic session, ICC = 0.91 in both cases) of the CT FNA-angle measurement method. This study suggests that CT FNA-angle measurement method is reliable and can be used in CT hip studies with confidence.

Keywords: Hip; Femur; Anteversion angle; CT; Dog; Canine hip dysplasia

1. Introduction

The femoral neck anteversion angle (FNA-angle) is the angle formed by the plane containing the axis of the femoral shaft and parallel to the transcondylar axis and the plane containing the axis of the shaft and the axis of the neck (Montavon et al., 1985). The long axis of the femoral shaft lies midway between the cortical borders, and the long axis of the neck is represented by a straight line passing through the centre of the femoral head and through the centre of the neck (Bardet et al., 1983).

The FNA-angle is important biomechanically in the transfer of forces from the femur to the acetabulum (Weigel and Wasserman, 1992). Large FNA-angles tend to rotate the femoral head out of the acetabulum and have been associated with hip dysplasia in humans (Anda et al., 1991; Hernandez, 1983), and with joint abnormalities present in spontaneous canine hip dysplasia (CHD) (Braden et al., 1990; Dueland, 1980; Nunamaker, 1974; Weigel and Wasserman, 1992). Simple and accurate evaluation of limb and pelvic conformation using computed tomography (CT) can be useful in CHD treatments (Dueland et al., 2001; Hara et al., 2002; Patricelli et al., 2002) and help understand the pathogenesis of osteoarthritis and CHD (Madsen and Svalastoga, 1994).

The complex three-dimensional configuration of the femur makes the FNA-angle measurement difficult (Montavon et al., 1985). In dogs, the FNA-angle can be measured using radiography by means of biplanar (Bardet

* Corresponding author. Tel.: +351 259350634; fax: +351 259350480.
E-mail address: mginja@utad.pt (M.M.D. Ginja).

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et al., 1983; Montavon et al., 1985) or fluoroscopic methods (Nunamaker et al., 1973), and in magnetic resonance imaging studies of the hip joint (Kaiser et al., 2001). Despite the use in some studies of CT in CHD prediction, treatment planning and monitoring, the FNA-angle has not been determined (Farese et al., 1998; Hara et al., 2002; Patricelli et al., 2002). In children, CT FNA-angle determination is indicated in CT hip studies when surgical procedures have to be performed (Hernandez, 1983).

The objectives of the present study were to describe and evaluate a new method for FNA-angle measurement using CT of the canine hip joints, and compare it to the standard radiographic biplanar method (SRBM).

2. Materials and methods

Twenty-three privately owned Estrela Mountain Dogs, between 7 and 8 weeks of age and weighing 6–10 kg (mean ± SD, 7.9 ± 0.9 kg) were used for the study. Dogs were premedicated with 0.02 mg/kg IM acepromazine (Vetranquil, Ceva Saúde Animal) and 0.2 mg/kg IM butorphanol (Torbugesic, Fort Dodge). Anaesthesia was induced with 5 mg/kg IV propofol (Diprivan, Zeneca), and maintained using inhalant isoflurane.

Computed tomographic images were obtained using a CT Tomoscan M-EG (Philips Medical System), with the dogs in sternal recumbency in a weight-bearing position on a foam rubber mould, similar to that described previously (Fig. 1) (Farese et al., 1998). Contiguous dorsal slices, with a thickness and index of 2 mm, were obtained from the femurs and the images were reconstructed in a 512 × 512 matrix and viewed in a bone window (window 1500; level 250). Three radiographs were taken of each dog, a standard ventrodorsal view of the pelvis with caudally extended femurs and a mediolateral view of each femur. After the examination, the dogs were clinically observed and returned to their owners.

The radiographs were digitalized using a computer scanner (ScanMaker 9800XL, Microtek) provided with a transparency adapter, and all measurements were performed using specific computer software (OSIRIS Imaging Software). The SRBM have been well described in previous studies (Bardet et al., 1983; Montavon et al., 1985). All the radiographic FNA-angles were calculated for every

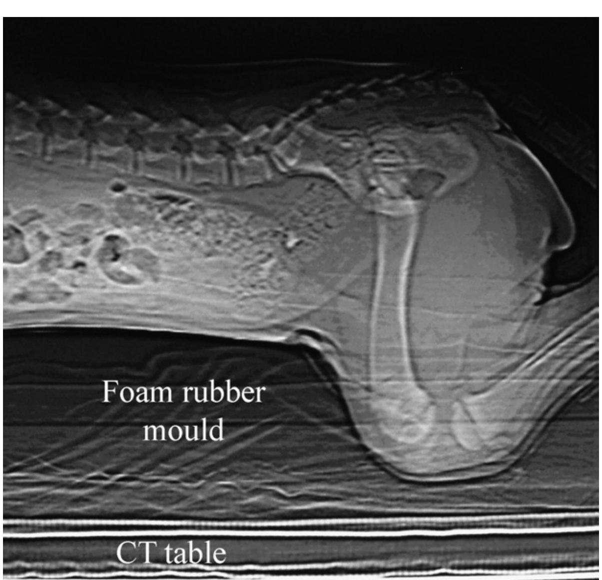

Fig. 1. Pilot CT image from a dog illustrating the position of the animal on the foam rubber mould.

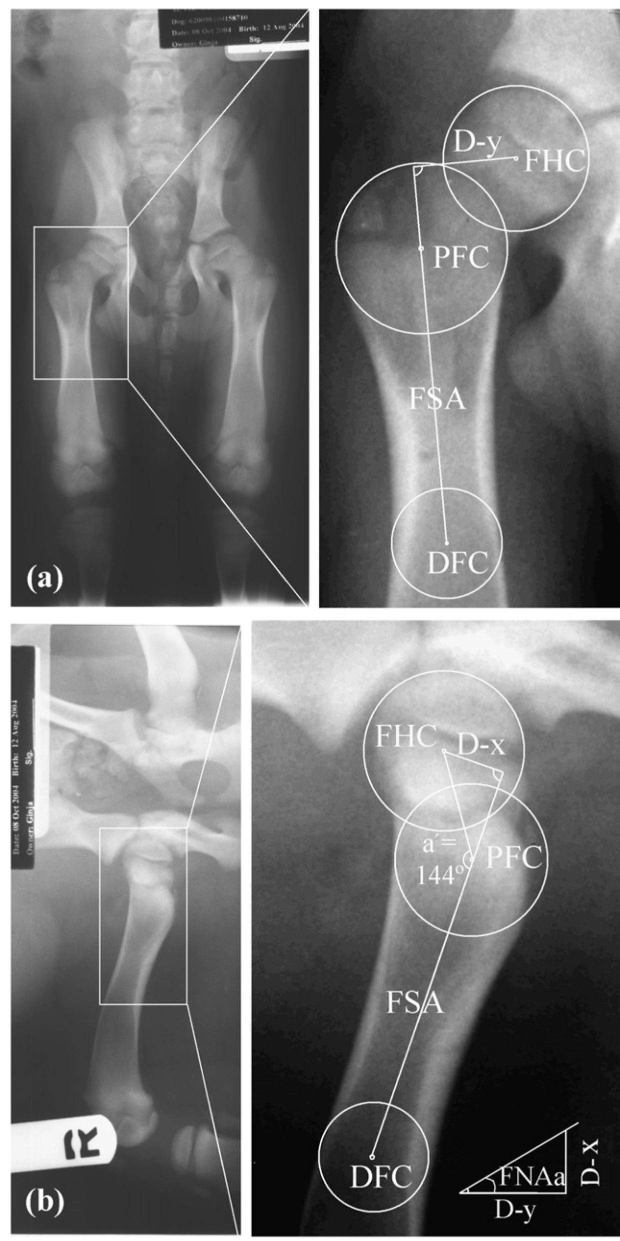

Fig. 2. Biplanar method of measuring the femoral neck anteversion: (a) Craniocaudal view. (b) Mediolateral view and the right-angled triangle constructed to measure the FNA-angle. (D-x) distance-x; (D-y) distance-y; (FNAa) femoral neck anteversion angle; (FHC) femoral head centre; (PFC) proximal femoral centre; (DFC) distal femoral centre; (FSA) femoral shaft axis; (a') angle between FSA and neck axis in sagittal plane.

hip by one examiner (MMDG), over the course of a session on two consecutive days.

The craniocaudal femoral view was used to determine the distance-y (D-y) as the perpendicular distance between the femoral head centre (FHC) and the extended femoral shaft axis (FSA). The FHC was determined by the centre of one circumference that encircled the femoral head, and the FSA was drawn connecting the centre of the two circumferences created with the diameter of the external cortical margin at the most proximal level of femoral shaft (PFC) and at the proximal third of the distal femoral half (DFC). The mediolateral radiographic view was used to determine the distance-x (D-x), as the perpendicular distance from FHC to the extended FSA. The FHC and the FSA in this view were established in the same way as in the craniocaudal view. The FNA-angle was measured as the tangent ($\tan D\text{-}x/D\text{-}y$) (Fig. 2).

All measurements of FNA-angle in the CT images were performed by one examiner (MMDG), maintaining the principal geometric and trigonometric relationships ($\tan D\text{-}x/D\text{-}y$). When the hip was in a neutral position, the FSA was drawn at the level of the CT slice containing the central area of the femoral shaft, connecting the centre of two circumferences created, with the diameter of the external cortical margin at the most proximal level of femoral shaft (PFC) and at the proximal third of the distal femoral half (DFC). The FHC was determined by the centre of one circumference drawn in the central femoral head slice (bisecting slice), which was copied and pasted (FHCp) onto the central femoral shaft slice (bisecting slice). The perpendicular distance between FHCp and the line of FSA is D-y, and D-x is equivalent to the number of slices between the central shaft slice and the FHC, multiplied by 2 mm (Figs. 3a and 4a).

When there was cranial or caudal positioning of FSA in the sagittal plane (hip flexion or extension, respectively) the D-y was measured in the same way in the slice of PFC (bisecting slice of the proximal femoral shaft, considered as a sphere) (Figs. 4a and b), but D-x was determined using the number of slices between PFC and FHC, the correction factors of flexion (CFflex) or extension (CFext), and the linear perpendicular distance between PFC and FHCp (Ld.1).

The degree of hip flexion or extension was determined as $\tan a/\text{Ld.2}$, where a is the number of slices between PFC and DFC (bisecting slice of the distal femoral shaft, considered as a sphere) multiplied by 2 mm and Ld.2 is the linear distance between PFC and DFC pasted (Figs. 3b and c). When there is hip flexion, D-x is equivalent to the arithmetical addition of the number of slices between FHC and PFC (mm) and the CFflex multiplied by Ld.1 (Fig. 4b), and in hip extension, D-x is equivalent to the arithmetical subtraction of the number of slices between FHC and PFC (mm) and the CFext multiplied by Ld.1 (Fig. 4c). The CFflex and CFext result from trigonometric mathematical expressions ($(\cos 54^\circ - \cos[54^\circ + \text{angle of hip flexion}])/\sin(54^\circ + \text{angle of hip flexion})$ and $(\cos 54^\circ - \cos[54^\circ - \text{angle of hip extension}])/\sin(54^\circ - \text{angle of hip extension})$ respectively (Table 1), where 54° is the mean angle between FSA and neck axis (90° + 54°) in the sagittal plane measured on radiographs in this breed (unpublished data) (Fig. 2b). We performed two CT measurement sessions, each on two days running and one week apart.

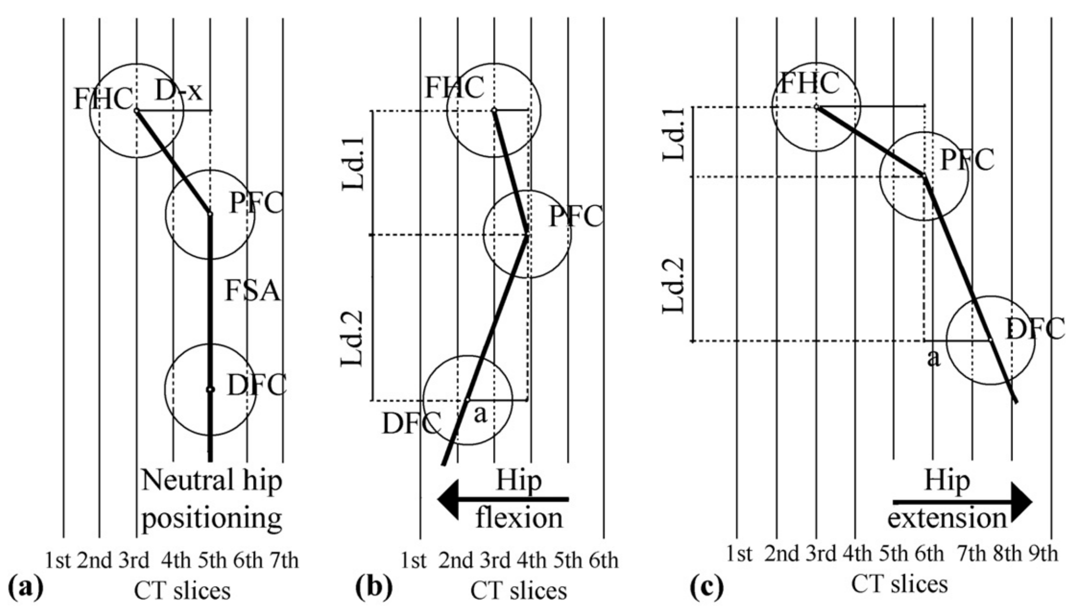

Fig. 3. Illustration outlining how the relationship between femoral head centre, and proximal and distal femoral centres vary in sagittal plane according to hip positioning: (a) Neutral hip positioning. (b) Hip flexion. (c) Hip extension. (D-x) distance-x; (FHC) femoral head centre; (PFC) proximal femoral centre; (DFC) distal femoral centre; (FSA) femoral shaft axis; (Ld.1) linear distance 1; (Ld.2) linear distance 2; (a') longitudinal distance between PFC and DFC in sagittal plane.

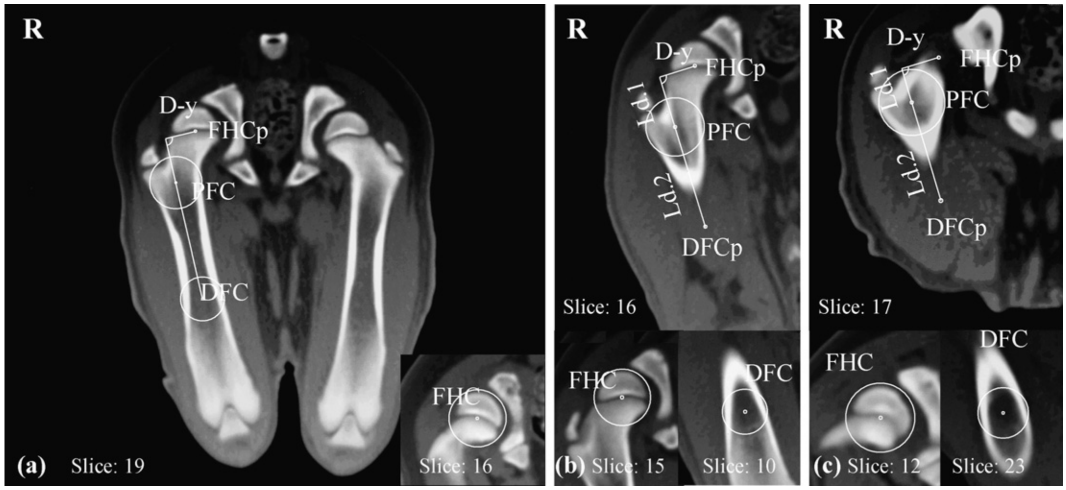

Fig. 4. Transverse CT hip images in a weight-bearing position: (a) Hip in neutral position; slice-19 contains the central area of the femoral shaft and slice-16 is at the level of the central area of the femoral head. (b) Hip flexion, slice-16 contains the central area of the proximal femoral shaft, slice-15 is at the level of the central area of the femoral head, and slice-10 is at the level of the central area of the distal femoral shaft. (c) Hip extension, slice-17 contains the central area of the proximal femoral shaft, slice-12 is at the level of the central area of the femoral head, and slice-23 is at the level of the central area of the distal femoral shaft. (R) right side; (FHC) femoral head centre; (FHCp) femoral head centre pasted; (*D-y*) distance-*y*; (PFC) proximal femoral centre; (DFC) distal femoral centre; (DFCp) distal femoral centre pasted; (Ld.1) linear distance 1; (Ld.2) linear distance 2.

Table 1
Hip flexion or extension angles up to 30° and corresponding correction factors, CFflex and CFext, respectively

Angles (°)	CFflex	CFext	Angles (°)	CFflex	CFext	Angles (°)	CFflex	CFext
1	0.02	−0.02	11	0.18	−0.21	21	0.34	−0.46
2	0.03	−0.04	12	0.20	−0.23	22	0.36	−0.49
3	0.05	−0.05	13	0.21	−0.25	23	0.37	−0.52
4	0.07	−0.07	14	0.23	−0.28	24	0.39	−0.56
5	0.08	−0.09	15	0.25	−0.30	25	0.40	−0.59
6	0.10	−0.11	16	0.26	−0.33	26	0.42	−0.63
7	0.12	−0.13	17	0.28	−0.35	27	0.44	−0.67
8	0.13	−0.15	18	0.29	−0.38	28	0.45	−0.71
9	0.15	−0.17	19	0.31	−0.40	29	0.47	−0.75
10	0.17	−0.19	20	0.32	−0.43	30	0.49	−0.80

(CFflex) Correction factor for hip flexion; (CFext) Correction factor for hip extension.

The intra-class correlation coefficient (ICC) was used to quantify the association between the two CT scoring sessions (repeatability), as well as between the radiographic session and the two CT sessions (reproducibility) (Lee et al., 1989). An ICC of 1 indicates perfect agreement and 0 indicates non agreement. The null hypothesis, that the correlation coefficients were equal to 0, was rejected at $P < 0.05$. Student's *t* test was used to compare the mean FNA-angle between measurement sessions. Statistical calculations were performed using standard computer software (SPSS Version 12.0).

3. Results

The FNA-angle (46 hips) using the SRBM ranged from 19° to 40° (mean ± SD, 29.9 ± 4.8°), in the first CT measurement session ranged from 20° to 41° (mean ± SD, 30.4 ± 4.2°), and the ICC was 0.91 (95% confidence interval [CI], 0.84–0.95). In the second CT session, the FNA-angle measurements ranged from 21° to 41° (mean ± SD, 30.5 ± 4.3°), and the ICC with the first CT measurement was 0.92 (95% CI, 0.86–0.96) and with the radiographic measurement was 0.91 (95% CI, 0.83–0.95). In all cases, the ICC were significantly different from 0 ($P < 0.001$) and the FNA-angle differences between groups were not significant in Student's *t* test ($P > 0.05$).

4. Discussion

The mean FNA-angles determined from both CT hip studies (30.4° and 30.5°) were similar to each other, to the SRBM (29.9°), and to the FNA-angles determined in other studies using the SRBM 31.3° (Bardet et al., 1983; Montavon et al., 1985). The specific CT landmarks used to determine FHC, PFC, DFC can be considered as standard. However, the ideal CFflex and CFext could have some breed variations, depending on the mean angle between FSA and neck axis in sagittal plane. The FNA-angle can be determined directly, by drawing a right-angled triangle, without needing trigonometric mathematical analysis (Bardet et al., 1983; Montavon et al., 1985) (Fig. 2b).

The SRBM was considered to be accurate in previous studies; the mean FNA-angle measured using the SRBM ($31.3 \pm 6.2°$) was similar to the direct bone measurement ($31.6 \pm 6.4°$), and differences between means were not significant in paired *t* tests (Montavon et al., 1985); it has been recommended for clinical use (Bardet et al., 1983; Ogata and Goldsand, 1979). In contrast, the mean FNA-angle in a previous study using magnetic resonance imaging was lower (<10°) than in the above mentioned studies, probably because the eccentric position of the femoral head and neck means the FHC lies cranially to the plane bisecting the femoral neck (Kaiser et al., 2001).

Our ICC results of 0.91 and 0.92 for reproducibility and repeatability, respectively, both with lower limits of 95% confidence interval above 0.75, without significant differences between the mean values in Student's *t* test, indicate that this CT method is reliable, and reproduces the radiographic SRBM with confidence (Lee et al., 1989). The dog preparation and the time required for radiographic and CT examinations are similar. The FNA-angle measurement in CT hip studies can be used for clinical or research purposes, without the need of additional radiographic exposures. However, new studies comparing the accuracy of the new CT measurement method and the SRBM will be important in proving which method is superior for determining the FNA-angle. For the time being, given that standard radiographic equipment is more easily available than CT in most veterinary institutions, the SRBM should be used for specific routine FNA-angle studies.

The FNA-angle determination in radiographic and CT measurement sessions was performed by just one individual to avoid scoring errors attributable to the examiner. These ICC indicate that there is some error in reproducibility and repeatability, which was <10% in each case and could be considered as acceptable in a measurement method. The high degree of agreement for the two CT measurements sessions was not surprising, given that CT is very reliable and accurate with regards to spatial dimensional data (Anda et al., 1991; Weiner et al., 1978). Certainly, some inaccuracy in CT reproducibility could be explained by scoring errors in SRBM, and some inaccuracy in CT repeatability could be attributed to the exact localization of specific landmarks (FHC, PFC, DFC). The repeatability of the CT method will improve when used in larger dogs, the errors in the exact localization of FHC, PFC and DFC will be less important in the larger *D-x* and *D-y* of these animals.

The positioning of dogs in the foam rubber mould allowed a good standardization of pelvic limbs, avoiding internal or external rotation of the hip. Some errors in FNA-angle measurements made with the SRBM are due to inaccurate positioning of patients when the radiographs are taken (Bardet et al., 1983; Ogata and Goldsand, 1979).
The determination of FSA inclination (degree of hip flexion or extension) will be used to better standardize CT hip studies in a weight-bearing position. The determination of the FSA line in craniocaudal and mediolateral femoral radiographic views using the circumference centres as reference was an modification to the original SRBM method (Bardet et al., 1983; Montavon et al., 1985), and based on the symmetric axis-method, recommended for use in determining the projected angle of inclination (Rumph and Hathcock, 1990). These authors have already suggested the use of the symmetric axis-method in the radiographic FNA-angle measurement. The FNA-angle estimate using computer software is easier if specific landmarks are determined by drawing circumference centres, instead of bisecting linear segments.

In conclusion, the CT method used to determine the FNA-angle, as described in the present study, is reliable and reproducible. The method improves the evaluation of hip and pelvic limb conformation in CT hip studies of CHD prediction or planning treatment (Farese et al., 1998; Hara et al., 2002; Patricelli et al., 2002), and could be useful in planning corrective rotational osteotomies of the femur, reconstruction of a complex femoral shaft or neck fractures, or other surgical hip treatments (Braden et al., 1990; Montavon et al., 1985; Nunamaker, 1974).

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