Analysis of Femoral Anteversion Angle in Canines and Humans: Establishing a Uniform Method for Clinical Use and Comparative Analysis

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INTRODUCTION: Anteversion (AV) angle of the proximal femur (Fig. 1A) is important in understanding the biomechanics of the human and canine hip [1-3]. AV angle correlates with hip dysplasia and secondary osteoporosis, and influences patellar luxation and hip joint reaction force. The canine femur has been used as a model for investigating pathology of the human hip, including prosthetic hip replacements for arthritis [2]. Because there are several methods for measuring AV angle in these two species there is considerable variation in AV angles reported in the literature (Table 1). This impedes comparative analyses and clinical interpretation. For example, Kuo et al. (2003) [3] noted this in their review of various methods used for measuring AV angle of human femora. They also evaluated variations in AV angle values obtained when using three methods on the same set of human femora: (1) direct measurements of the bone (the "gold standard"), (2) computed tomography (CT) imaging (simulating current clinical methods and the gold-standard direct measurement method), and (3) biplane radiography in accordance with the historical, and still used, clinical biplane radiographic method of Ogata et al. [4]. They found that CT imaging methods have substantially greater accuracy and reliability when compared to biplane radiograph methods. Notably, compared to variations in reported human AV values, variations in canine AV values are often greater (Table 1). This is because the gold-standard method in dogs has been the study of Montavon et al. [5] wherein x and y offsets (Fig. 1B,C) obtained from biplane radiographic images are then plotted on a normogram (not shown) to obtain the AV angle. One problematic aspect of the Montavon method is that it does not use distal femoral torsion (Fig. 1A), which is fundamental in the gold-standard methods (i.e., direct measurement or CT scan). What also leads to confusion in published canine AV values is that some studies of AV do consider distal femoral torsion, thus mirroring the gold-standard methods commonly used in human biomechanical and clinical studies. For example, and compared to Montavon et al., the canine femoral AV studies of Dudley et al. [6] and Mostafa et al. [7] used methods that rely on distal femoral torsion. Similar to the now common method employed for human femora, they measured AV angle using CT images of the distal femoral condyles as well as of the head, neck, and greater trochanter. In the present study we sought to show why the biplane radiographic method of Montavon et al. [5] should no longer be used, and that past studies that have employed it must be cautiously considered because it often exaggerates canine femoral AV angle when compared to the CT or direct measurement methods.

METHODS: AV angles were measured on 10 adult greyhound femora that were obtained from our prior studies [1,2]. The AV angles were measured according the methods of Montavon et al. [5] (biplane radiographs) and Kuo et al. [3] (CT image measurements, which closely match direct measurements). Anatomical orientation of the femora was done in accordance with [2]. Figure 1B and C illustrate the x and y offset measurements used in determining the AV angle using biplane radiographs in accordance with the Montavon method. For the CT method, transverse images (more than one if needed) were taken through the proximal femur, and included the femoral neck and head; another image was taken transversely through the distal ends of the epicondyles. The distal and proximal images were then superimposed on an illuminated view box and the AV angle was measured with a transparent protractor. This CT method is similar to that used by Dudley et al. [6] and Mostafa et al. [7] and is also shown diagrammatically in Fig. 1A. Two observers independently measured each of the bones using each of the methods. In order to demonstrate similar overall proximal morphology of the bones used, cervico-diaphyseal (CD) angles are also measured directly from the bones [1].

RESULTS: The AV angles obtained on the 10 greyhound femora are shown in Table 2. Notably, most bones had similar CD angles. The Montavon AV values range from 12.5 to 28.0 degrees (mean: 19.7; SD: 5.4), and the AV values obtained using CT images range from 7.5 to 21.0 degrees (mean: 14.3; SD: 3.8) (see CT-Obs 1 and 2 at the far right of Table 2; Obs = observer). When compared to each other, the values obtained by the two observers were not significantly different ($p = 0.6$). The AV angles measured by the Obs 1 and Obs 2, however, significantly differ from the AV angles obtained using the Montavon method ($p = 0.006$ and <0.001, respectively. These results show that, when compared to the Montavon AV values, the AV values obtained from the CT image measurements are on the order of 5 to 10 degrees lower (~ to % lower) in 8 of the 10 bones.

DISCUSSION: Differences in these two methods reflect the fact that distal femoral torsion is not used in the biplane radiographic method of Montavon et al. [5]. This leads to exaggeration of the femoral AV angle in a large majority of cases. In their study of human femora, Kuo et al. [3] similarly found increased AV values when using biplane radiography compared to CT imaging. Using a technique similar to the CT image method used in the present study, Dudley et al. [6] and Mostafa et al. [7] also show a lower average AV angle in canines when compared to the several prior studies that utilized the Montavon method. When distal femoral torsion is used in the CT image method there is relatively less variability in the AV angles (Table 2). Additionally, and similar to our results, Dudley et al. also showed that CT image methods yielded lower AV angles than biplane radiography. The AV angles obtained when using CT images also mirror the AV angles made when directly measuring the bones. In view of our results, we propose that the CT image method that we employed should be the gold standard for measuring canine and human femoral AV angles.

SIGNIFICANCE: Distal femoral torsion can have a significant impact on femoral anteversion (AV) angle. Methods of measurement that consider this provide more accurate results for clinical use and comparative analysis in canines and humans.

REFERENCES: 1. Kuo et al. (1998) *J. Biomedical Materials Res* 40:475-489; 2. Bloebaum et al. (1993) *J. Biomedical Materials Res.* 27:1149-1159; 3. Kuo et al. (2003) *Investigative Radiology* 38:221-229; 4. Ogata et al. (1979) *J. Bone Joint Surg Am.* 61:846-851; 5. Montavon et al. (1985) *Veterinary Surgery* 14:277-282; 6. Dudley et al. (2006) *Veterinary Radiology & Ultrasound* 47:546-552; 7. Mostafa et al. (2014) *Veterinary Surgery,* 43:534-541.

	Measurement Technique	Author	Degrees of Anteversion	Year Published	Sample
Canine Measurements	Radiographic Biplanar	Montavon	31.3 +/- 6.2	1985	30 mature mongrel dogs
	CT	Mostafa	28.0 +/- 4.9	2014	30 mature, pure bred labrador retrievers
	Radiographic Biplanar	Dudley	16 +/- 6.4	2006	9 medium to large, mixed breed dogs, 20-30 kg
	CT		19.6 +/- 7.9		
	Direct Measurement		18.9 +/- 5.4		
Human Measurements	Radiographic Biplanar	Kuo	23.1 +/- 6.9	2003	10 normal adult cadaveric human femora, mean age of 47
	CT		12.4 +/- 3.8		
	Direct Measurement		9.6 +/- 3.3		

Table 1. Summary table of different methods.

Specimen	Montavon				CT Imaging	
Accession #	*x (mm)*	*y (mm)*	*AV (degree) using Fig 5 grid from Montavon et al.*	*CD (degree)*	*AV (degree) Observer 1*	*AV (degree) Observer 2*
D178-88R	5.0	17.0	17.0	130.0	10.0	9.0
D47-88R	7.0	18.0	21.0	135.0	16.0	16.0
D244-89R	3.5	18.0	16.0	130.0	13.0	11.5
D58-88R	9.0	20.0	24.5	130.0	15.0	18.0
D177-88R	9.5	17.5	28.0	125.0	14.0	17.5
D177-88L	8.0	20.0	22.0	128.0	15.0	14.0
D176-88R	5.0	19.5	14.5	135.0	14.5	14.0
D242-89R	9.0	18.0	26.0	136.0	22.5	21.0
D88-88R	4.5	19.5	12.5	129.0	15.0	12.5
D88-88L	5.0	17.5	15.0	134.0	9.0	7.5

Table 2. Results of the present study. For brevity, only one observer's data is shown for the Montavon et al. method.

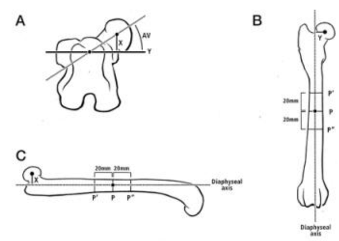

Figure 1. A: Method used with CT imaging as described by Kuo et al. (1998). The "Y line" parallels the posterior aspects of the femoral condyles (i.e., at the lower aspect of the drawing).
B and C: Drawings depicting the methods used to obtain the offset values (x and y) as described by Montavon et al. (1985).