doi: 10.17221/2/2016-VETMED

A radiographic and anatomic study of caudolateral curvilinear osteophytes on the canine femoral neck

L. Pyszkova, M. Pyszko, V. Paral, F. Tichy, M. Kyllar*

Faculty of Veterinary Medicine, University of Veterinary and Pharmaceutical Sciences, Brno, Czech Republic

*Corresponding author: kyllarm@yahoo.com

ABSTRACT: Caudolateral curvilinear osteophytes (CCOs) are considered to be an important finding for the early detection of canine hip dysplasia. The objective of this study was to determine the association between the radiographic and anatomic appearance of CCOs, and to determine whether CCOs are indicative of osteoarthritis. One hundred canine femurs were used to determine the topographical location of CCOs on the femoral neck, and the anatomic and radiographic presence of CCOs and their association with weight, sex, osteoarthritis, and femoral morphometry. Three angles were calculated to assess femoral conformation. The alpha angle and gamma angle described the angulation of the proximal femur and femoral neck, respectively. The beta angle described the angulation of the distal femur. Anatomic CCO was not detected in four femurs. No radiographic CCO was detected in 35 femurs and osteoarthritis changes were not found in 30 femurs. Statistically significant relationships were observed between anatomic CCO, alpha angle, and gamma angle. Statistically significant associations were observed between radiographic CCO, alpha angle, and gamma angle. The results of this study support an association between radiographic CCO on the femoral neck and osteoarthritis changes in the proximal femur. It can also be concluded that CCOs develop in association with femoral neck angulation, and may therefore be considered as an adaptation to the forces created by body weight that act through the femoral neck.

Keywords: hip laxity; femoral luxation; hip dysplasia; osteoarthritis

Canine hip dysplasia (CHD) is a highly prevalent, progressive, and frequently debilitating disease in dogs. The prevalence of CHD is as high as 73% in some breeds of dogs (Paster et al. 2005; Genevois et al. 2007; Genevois et al. 2008; Doskarova et al. 2010; Martins et al. 2012). Radiographic and clinical evidence of coxofemoral osteoarthritis is a common sequela of CHD, and is mostly apparent in older dogs (Whittington et al. 1961; Ackerman 1982; Morgan 1987; Owens and Biery 1999; Mayhew et al. 2002). Current screening systems for CHD rely on radiographic interpretation by quantification of certain anatomic landmarks of the hip joint serving as assessment criteria. These significantly affect final assessment score and, therefore, their efficacy in reducing or eradicating CHD is limited (Fluckiger et al. 1995; Willis 1997; Doskarova et al. 2010). Despite intensive screening for more than four decades, the prevalence of CHD remains high in some breeds of dogs (Paster et al. 2005; Coopman et al. 2008; Doskarova et al. 2010; Martins et al. 2012). Environmental factors such as weight, exercise regimen, sex, and breed have been reported to affect hip joint growth and subsequent development of CHD (Whittington et al. 1961; Ackerman 1982; Mayhew et al. 2002; Paster et al. 2005; Genevois et al. 2007; Genevois et al. 2008; Doskarova et al. 2010).

The first radiographic evidence of CHD has been described to be femoral head subluxation and a lag in the development of the acetabular rim that can be detected as early as 30–60 days of age (Riser et al. 1985). Subluxation of the coxofemoral joint during weight-bearing has been suggested to ex-

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ert tension on the joint capsule, leading to trauma and joint capsule thickening, and the formation of an osteophyte at the site of joint capsule attachments (Riser et al. 1985). An example of such an osteophyte is the caudolateral curvilinear osteophyte (CCO) on the femoral neck (Whittington et al. 1961; Riser et al. 1985; Mayhew et al. 2002; Powers et al. 2004; Kishimoto et al. 2010), which has also been referred to as Morgan's line (Morgan 1987). The CCO appears as a radiopaque curvilinear line that varies in size (Kishimoto et al. 2010). On ventrodorsal hip-extended radiographs, the CCO is superimposed on the caudolateral surface of the femoral neck. Recognition of this early radiographic sign has been reported to potentially aid in clinical decisions regarding juvenile pubic symphysiodesis, dietary management, or rejection as breeding stock by 16–20 weeks of age (Riser et al. 1985; Adams et al. 1998; Torres et al. 1999; Adams et al. 2000; Vezzoni et al. 2008; Kishimoto et al. 2010). However, the diagnostic significance of the CCO remains debatable, and, since first described in 1961, the importance of the CCO as an early indicator of CHD has been rather controversial (Whittington et al. 1961). Several reports do not consider the CCO to be indicative of osteoarthritis or CHD in the absence of subluxation or other radiographic signs of osteoarthritis, and a number of radiologists have dismissed these projections as incidental findings (Adams et al. 1998; Vezzoni et al. 2008). Recent evidence indicates that dogs with CCO are 7.9 times more likely to have definitive radiographic signs of osteoarthritis (Mayhew at al. 2002).

The objective of this study was to determine the association between the anatomic and radiographic appearance of CCOs, and to determine whether CCOs are indicative of osteoarthritis or whether they represent an adaptation or anatomical feature of the proximal femur.

MATERIAL AND METHODS

Fifty client-owned dogs euthanised for reasons unrelated to this study were investigated. Both femurs were used from each dog. The complete clinical history was obtained, and dogs with a history of trauma or previous surgery on the pelvis, hip joint, or the femur were excluded from the study. Dogs were divided into three groups based on their body weight (Table 1).

Table 1. The study population of dogs and their division into groups based on their weight and sex

	< 10 kg	10.1–25 kg	> 25.1 kg	Total
Male	5	11	13	29
Female	3	7	11	21
Total	8	18	24	50

Both femurs were harvested following euthanasia. The topographic location of the CCO relative to the joint capsule attachment was assessed following dissection of the hip joint (Figure 1). Following macroscopic evaluation, the femurs were stripped of soft tissue and underwent a biological maceration process.

Maceration was performed through immersion in water at room temperature for 60 days followed by degreasing in a soap solution (Jar, Henkel, Hungary) for seven days. Finally, 10% oxygen peroxide was used to produce bleached bones.

The degreased and bleached femurs were assessed for the presence and size of anatomic CCOs (aCCOs) using the following grading system: 0 = no aCCO detected; 1 = tiny aCCO present (less than 1 mm); 2 = small aCCO present (1–2 mm); and 3 = moderate aCCO present (> 2 mm) (Figure 2). The size of the aCCOs was determined using callipers that measured from the surface of the bone to the highest point of the CCO. For radiographic assessment of

Figure 1. Topographic location of a caudolateral curvilinear osteophyte (CCO) on the femoral neck in relation to the insertion of the joint capsule. The white arrow indicates the location of the CCO, and the black arrow indicates the insertion of the joint capsule on the femoral neck. Proximo-caudal view of the femoral neck and head

doi: 10.17221/2/2016-VETMED

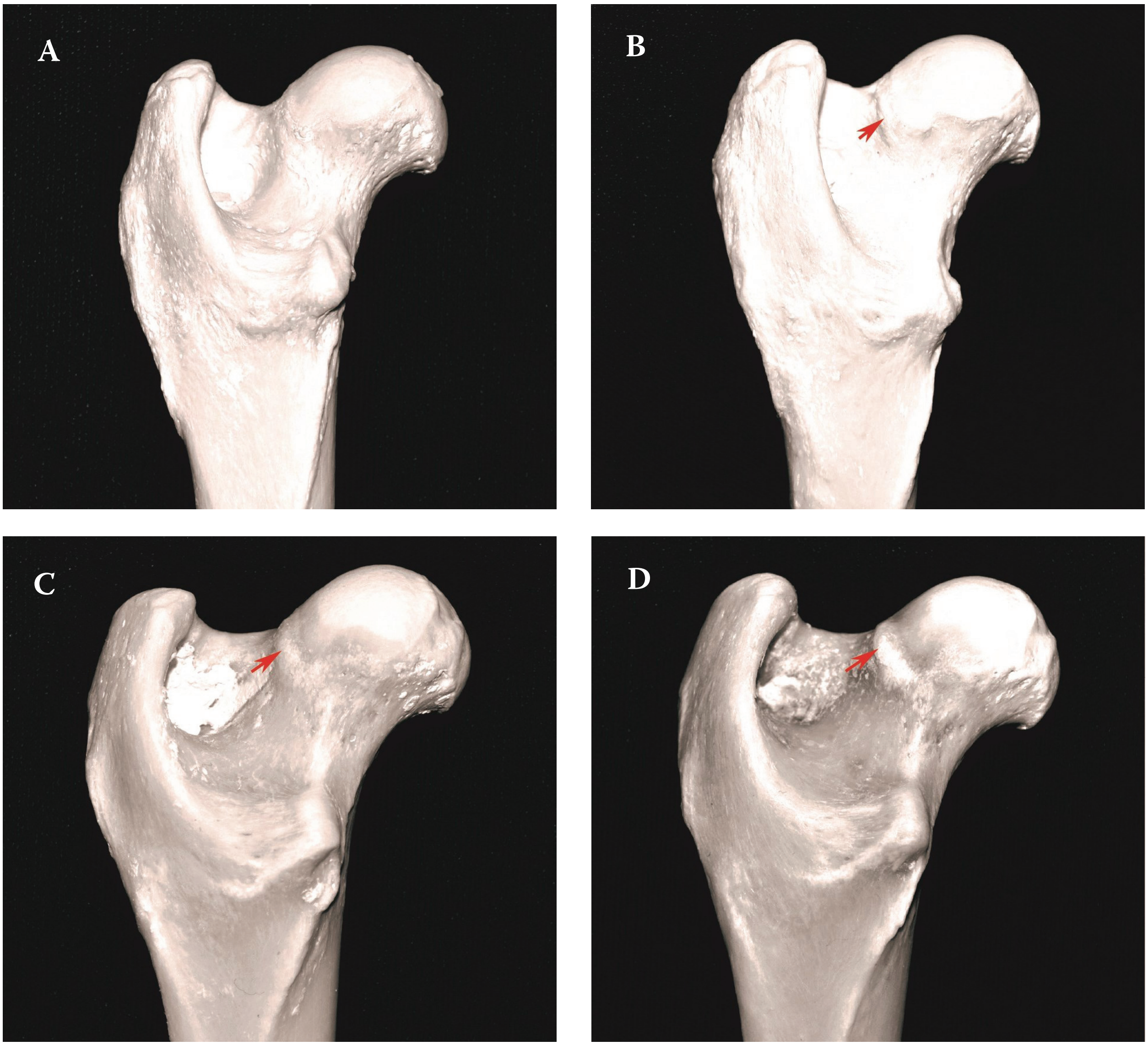

Figure 2. Assessment of different grades of caudolateral curvilinear osteophyte detected in anatomical specimens (aCCO) of the canine femur. The arrows indicate the highest point measured from the surface of the bone

A = grade 0: no aCCO detected, aCCO = anatomic caudolateral curvilinear osteophyte, B = grade 1: tiny aCCO present (< 1mm in height), C = grade 2: small aCCO present (1–2 mm in height), D = grade 3: moderate aCCO present (> 2 mm in height)

the CCO, the femurs were placed on a radiographic cassette that enabled the long axis of the femur to be positioned parallel with the table top (cranio-caudal projection of the femur), resembling the extended hip view used in the Orthopaedic Foundation of America screening for hip dysplasia (Figure 3). Radiographs were taken separately for each femur. Femurs were radiographed using a Proteus X-ray machine (GE Healthcare, Milwaukee, Wisconsin, USA). Radiographic images were taken on computed radiography cassettes (size, 35 × 43 cm) with the focal length set to 100 cm, and with exposition values of 60 kV, 500 mA, and 250 ms (125 mAs). Images were stored in DICOM format using a computed radiography system (FCR Capsula XL, Fuji, Tokyo, Japan). The image resolution was 1760 × 2140 pixels.

Each radiograph was assessed for the presence of osteoarthritic changes using a grading system from 0 to 3 (Figure 4). The presence of radiographic CCO (rCCO) was graded as follows: 0 = no rCCO detected; 1 = tiny rCCO present; 2 = small rCCO present; and 3 = moderate rCCO present (Figure 5). Assessment of osteoarthritic changes and determination of the presence of aCCO and rCCO were

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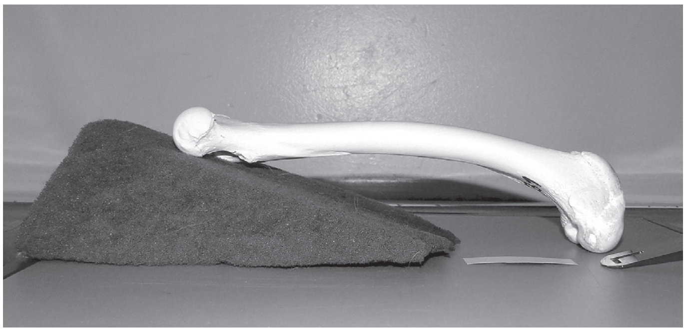

Figure 3. Positioning of macerated canine femurs for radiography. A foam wedge was used to position the long axis of the femur parallel to the radiographic cassette. A table-top technique for obtaining cranio-caudal radiographs was used

carried out by a single reader. Morphometric assessment of the functional femoral alpha angle (Figure 6), anatomic femoral beta angle (Figure 7), and gamma angle of the femoral neck (Figure 8) were performed. Functional alpha angle was determined as the angle between the functional femoral

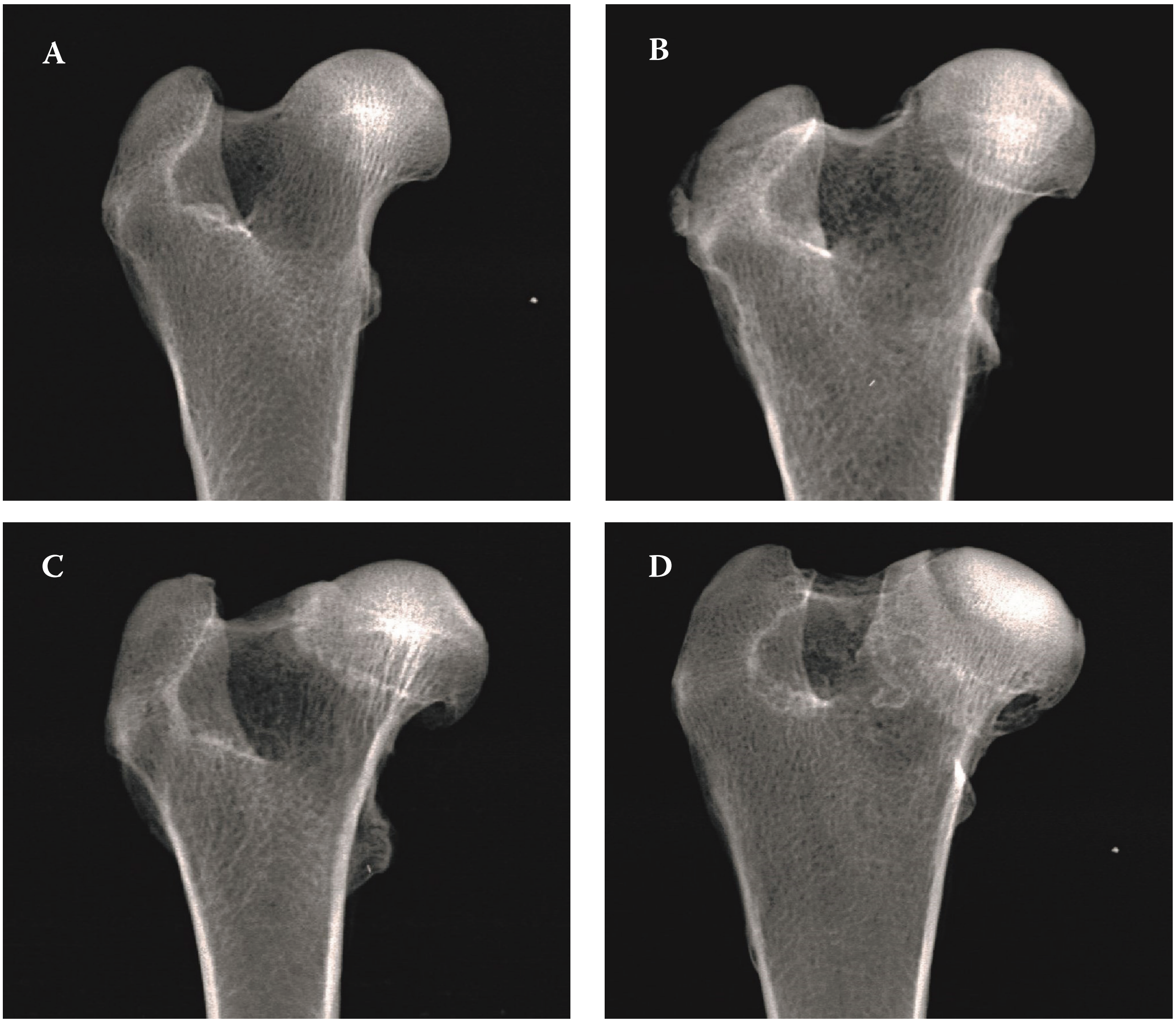

Figure 4. Assessment of radiographic grades of osteoarthritic changes on canine femur. Cranio-caudal view of the proximal femur

A = grade 0: smooth femoral head and neck contours, B = grade 1: osteophytic formation around the dorsal rim of the femoral neck, C = definite osteophyte on the dorsal aspect of the femoral neck and around the femoral head, D = grade 3: large osteophytes, sclerosis, and definite deformity of the bone contour

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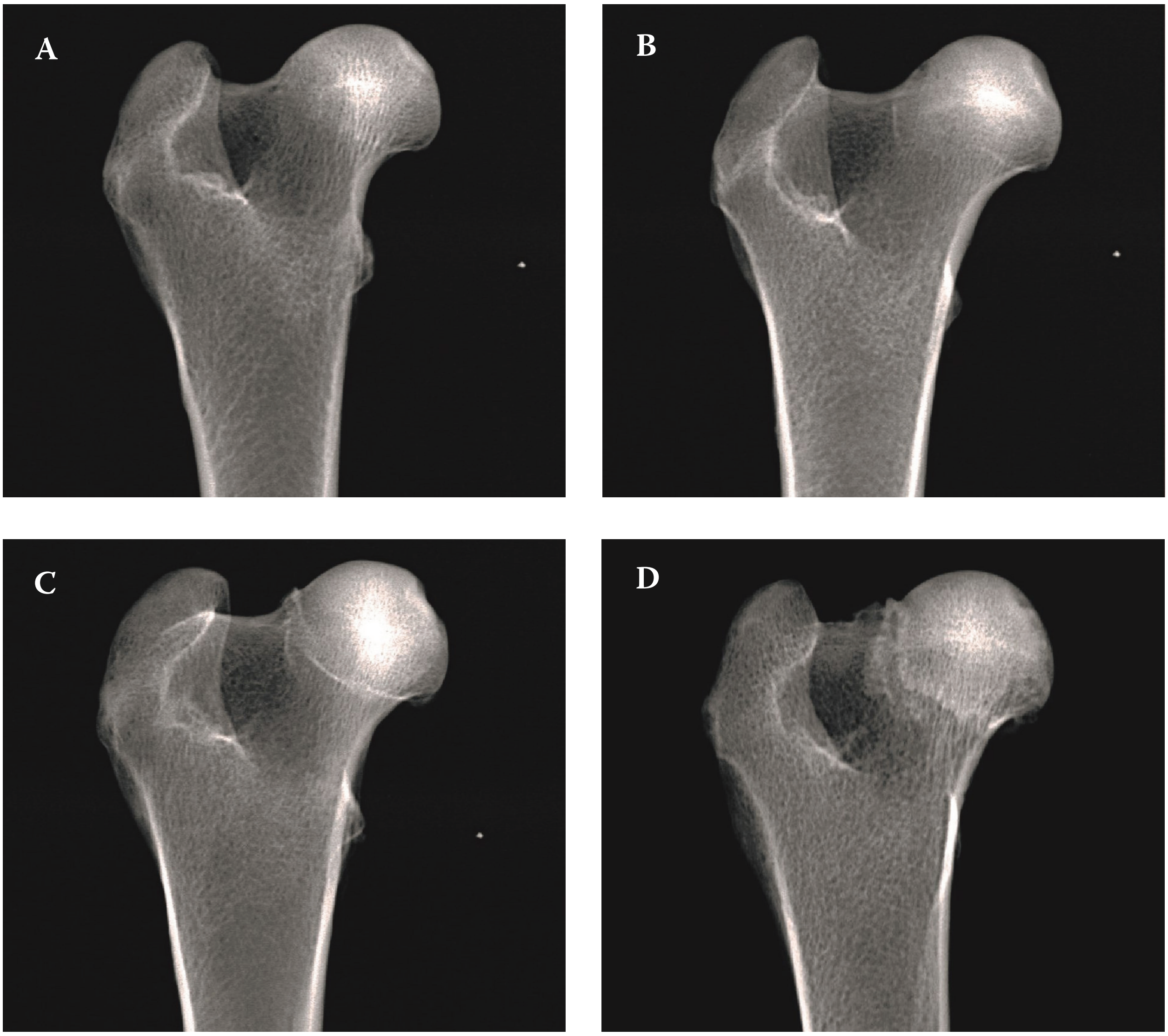

Figure 5. Assessment of the radiographic presence of a caudolateral curvilinear osteophyte on canine femur. Craniocaudal view of the femoral head. Arrowheads indicate location of the CCO
A = 0: no rCCO detected, B = 1: tiny rCCO present, C = 2: small rCCO present, D = 3: moderate rCCO present, rCCO = radiographic caudolateral curvilineal osteophyte

axis and tangent to femoral condyles. The functional femoral axis was defined as a line connecting the centres of the femoral head and, in the form of a tangent to the femoral condyles, a line connecting the distal prominences of femoral condyles.

The anatomic beta angle was established as the angle between the anatomic femoral axis (Figure 7) and a tangent to the femoral condyles. The anatomic femoral axis was defined as a line connecting the centres of the femoral shaft and the trochlea, and, in the form of a tangent to the femoral condyles, a line connecting the distal prominences of the femoral condyles.

Angle gamma was determined as the angle between the axis of the femoral neck and a line connecting the trochanter minor and the bottom of the fossa trochanterica. The femoral neck axis was defined as a line connecting the centre of the femoral head with a point halfway between the bottom of the fossa trochanterica and trochanter minor. Three measurements were taken for each value and the average of these was used for further calculations. All measurements were performed by a single reader.

Statistical analysis. In this study, we used two dependent variables: rCCO and aCCO. The independent variables included sex, age, weight group,

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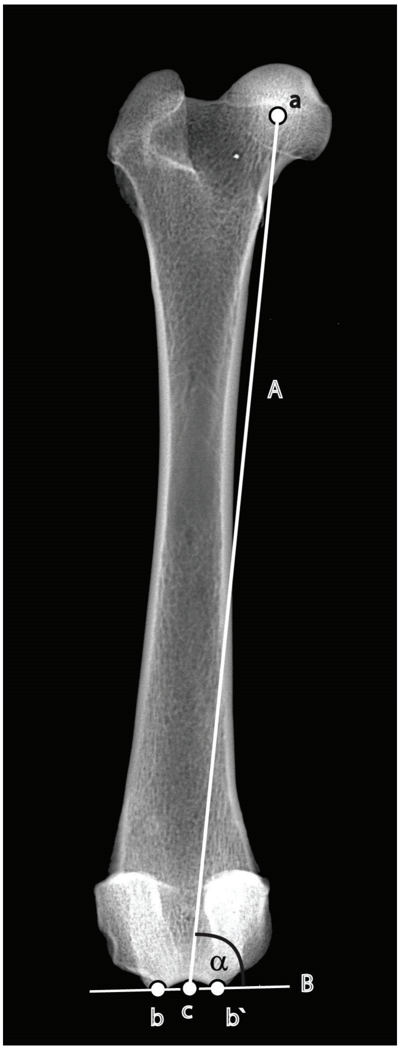

Figure 6. Morphometric assessment of the functional femoral angle alpha (α) (Cranio-caudal radiograph of the femur). Functional femoral axis (A) was defined as a line connecting the centres of the femoral head (a), and the trochlea (c), and tangent to the femoral condyles (B) as a line connecting the distal prominences of femoral condyles (b and b')

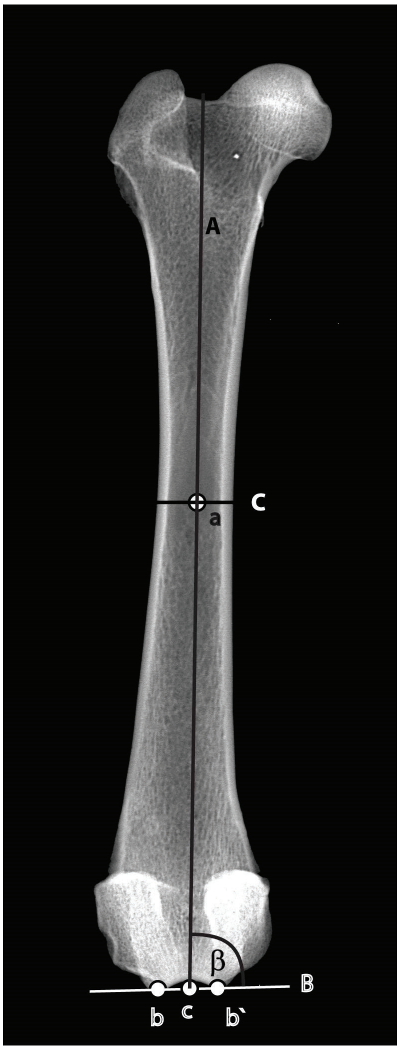

Figure 7. Morphometric assessment of the anatomic femoral beta angle (β) (Cranio-caudal radiograph of the femur). Anatomic femoral axis (A) was defined as a line connecting the centres of the midshaft of the femur (a) and the trochlea (c), and as a tangent to the femoral condyles (B), a line connecting the distal prominences of femoral condyles (b and b')

Figure 8. Morphometric assessment of the femoral neck gamma angle (γ) (cranio-caudal radiograph of the femur). The gamma angle was the angle between the axis of the femoral neck (A) and a line (B) connecting the trochanter minor (b) and the bottom of the fossa trochanterica (c). The femoral neck axis (A) was defined as a line connecting the centre of the femoral head (a) with a point (d) halfway between the bottom of the fossa trochanterica and the trochanter minor

alpha angle, beta angle, gamma angle, and osteoarthritis scores. Responses for both dependent variables were regarded as ordinal. Ordinal logistic regressions, specifically, proportional odds models, were proposed to investigate the effects of the independent variables on each of the dependent variables.

The chi-squared test (χ^2) was used to analyse the validity of the proportional odds assumption. A non-significant test result (P-value > 0.05) indicated that the proportional odds assumption was satisfied. The Wald χ^2 test was used to determine if an effect was statistically significant. All data analyses were conducted using SAS (Statistical Analysis System; North Carolina, USA).

doi: 10.17221/2/2016-VETMED

Table 2. Frequency distribution of the three weight groups, sex, osteoarthritis score, caudolateral curvilinear osteophyte presence by radiography, and caudolateral curvilinear osteophyte presence by anatomy, in dogs

		Frequency (%)
Weight group	< 10 kg	8 (16)
	10.1–25 kg	18 (36)
	> 25.1 kg	24 (48)
Sex	male	29 (58)
	female	21 (42)
OA grade	0	30 (60)
	1	9 (18)
	2	5 (10)
	3	6 (12)
rCCO grade	0	35 (70)
	1	10 (20)
	2	2 (4)
	3	3 (6)
aCCO grade	0	4 (9)
	1	16 (36)
	2	17 (39)
	3	7 (16)

aCCO = anatomic caudolateral curvilinear osteophyte, OA = osteoarthiritis, rCCO = radiographic caudolateral curvilinear osteophyte

RESULTS

We evaluated 100 femurs in this study. No aCCO was detected in four femurs. In 35 femurs, no rCCO was found, and no osteoarthritis changes were observed in 30 femurs. Table 2 lists the frequency distribution of the weight, sex, osteoarthritis scores, rCCO presence, and aCCO presence. Table 3 describes the summary statistics of the different variables.

Presence of aCCO in canine femurs

Femurs from only 44 dogs were used for logistic regression analysis as the presence of CCO could not be established in six dogs due to changes arising from severe osteoarthritis (grade 3). No statistically significant relationships were observed between aCCO grade and sex (P = 0.1789), osteoarthritis score (P = 0.4919), age (P = 0.1091), alpha angle (P = 0.0944), and beta angle (P = 0.8051). Statistically significant relationships were found between aCCO grade, weight (P = 0.0247), and gamma angle (P = 0.0417). The strength of the relationship between the two variables was interpreted using the odds ratios. The odds ratios and the confidence interval are presented in Table 4. If the confidence interval did not contain a numerical value of 1 in its range, then the effect was significant, and corresponded to the results of the Wald χ^2 test.

Table 3. Summary statistics of the distribution of age, and the femoral alpha, beta, and gamma angles

	Mean	SD	Median	Min.	Max.
Age (months)	93.40	45.01	102	6	168
Alpha angle	83.32°	3.65	83.45°	75.20°	93.80°
Beta angle	88.58°	2.92	88.55°	83.40°	97.30°
Gamma angle	90.37°	7.09	91.50°	64.80°	103.50°

Table 4. Odds ratio estimates and 95% confidence limits for anatomic caudolateral curvilinear osteophytes

	Odds ratio	CI
Weight group*	19.360	1.423–265.215
Sex	0.358	0.048–4.250
Osteoarthiritis score	16.780	0.748–287.748
Age	0.880	0.935–1.238
Alpha angle	0.338	0.325–1.875
Beta angle	0.287	0.835–1.275
Gamma angle*	1.746	1.348–1.875

*P < 0.05

The odds ratio of weight was 19.36 (95% CI 1.423–265.215) indicating that dogs with low weight were more likely to experience a lower aCCO grading. The odds ratio of gamma angle (odds ratio = 1.746; 95% CI 1.348–1.875) indicated that dogs with lower gamma angle values were less likely to experience lower aCCO grading than dogs with higher gamma angle values.

Table 5. Odds ratio estimates and 95% confidence intervals for radiographic caudolateral curvilinear osteophytes

	Odds ratio	CI
Weight group*	16.031	1.898–286.245
Sex	0.493	0.067–3.650
Osteoarthiritis score*	25.296	1.904–336.067
Age	0.954	0.919–1.290
Alpha angle*	0.345	0.090–0.689
Beta angle	0.309	0.083–1.147
Gamma angle*	1.346	1.576–1.967

*P < 0.05

doi: 10.17221/2/2016-VETMED

Presence of rCCO in canine femurs

For logistic regression, femurs from 50 dogs were used. No statistically significant associations were found between rCCO presence and sex (P = 0.4791), age (P = 0.1121), and beta angle (P = 0.8051). Statistically significant relationships were observed between rCCO and weight (P = 0.0238), radiographic osteoarthritis score (P = 0.0419), alpha angle (P = 0.0434), and gamma angle (P =0.0417).

The strength of the association between the two variables was interpreted using the odds ratio. The odds ratios and the CI are presented in Table 5. The odds ratio of weight was 16.31 (95% CI 1.898–286.245) and indicates that heavier dogs were less likely to experience a lower rCCO grading than lighter dogs. The odds ratio of alpha angle was 0.345 (95% CI 0.090–0.689) and indicates that dogs with a higher angle alpha reading were less likely to experience a lower rCCO grading than dogs with lower alpha angle readings. The odds ratios of gamma angle (odds ratio = 1.346; 95% CI 1.576–1.967) indicated that dogs with lower gamma angle values were less likely to experience a lower rCCO grading than dogs with a higher angle gamma reading. No association was found between the presence of aCCO and rCCO on the proximal femur.

Topographical evaluation

All observed CCOs were located on the caudolateral aspect of the femoral neck and were located within the joint space. There was no association of CCO presence with the attachment of the joint capsule.

DISCUSSION

The CCO, occasionally referred to as Morgan's line (Morgan 1987), is considered to be an important finding in the early detection of CHD and for the diagnosis of hip subluxation (Torres et al. 1999; Paster et al. 2005). However, its diagnostic significance remains debatable as several reports do not consider the CCO as a diagnostic criterion and suggest that further evaluation of its diagnostic utility and significance is required (Adams et al. 1998; Mayhew et al. 2002; Powers et al. 2004). The objective of this study was to assess a possible association between CCOs and the angulation of the femur, osteoarthritis, age, sex, and weight. Furthermore, we compared the presence of CCOs in cadaver bones and on radiographs.

The importance of CCOs on the femoral neck in dogs was first described by Morgan (1987). The stress caused by the insertion of the joint capsule into the hip joint has been postulated to be an important factor in its aetiology. Several studies, including that of Morgan (1987), have reported that remodelling of the joint capsule occurs and leads to the formation of osteophytes or enthesophytes (Mayhew et al. 2002; Powers et al. 2004; Szabo et al. 2007). The topographical findings of our study showed that the CCOs are caudolaterally located on the femoral neck within the joint cavity and not at the insertion of the joint capsule. This finding suggests that the CCO cannot be considered as an enthesophyte as it is not part of the joint capsule attachment.

The results of our study support an association between rCCO on the femoral neck and osteoarthritis changes in the proximal femur. This is in agreement with another study that described an association between rCCO and development of osteoarthritis (Mayhew et al. 2002). Furthermore, it has been reported that dogs with rCCO were found to have as much as a 7.9 times higher risk of exhibiting radiographic signs of osteoarthritis compared with dogs without CCO (Mayhew et al. 2002). Several studies have reported no association between rCCO and subsequent development of osteoarthritis (Adams et al. 1998; Adams et al. 2000). However, no association was observed between aCCO and osteoarthritis changes. These differences may be explained in two ways. First, there may be a lack of association between the CCO and osteoarthritis, and a number of dogs may develop osteoarthritis without the CCO serving as an early feature or indicator of osteoarthritis. This may indicate that some dogs had CCO that was obscured by the presence of osteoarthritis and were, therefore, not assessed as having a CCO. Second, the presence of CCO may be breed-specific. However, some studies argue that CCO may represent a sign of predisposition to hip dysplasia development, and it may be mitigated or offset by environmental factors (Torres et al. 1999; Powers et al. 2004; Paster et al. 2005).

In our study, the presence of both rCCO and aCCO was associated with the morphometry of the femur, providing further support for the presence of CCO in relation to possible development of osteo-

doi: 10.17221/2/2016-VETMED

arthritis. This study revealed that femurs with larger gamma angles were likely to have less pronounced aCCO and rCCO on the femoral neck. Furthermore, a larger alpha angle was predictive of pronounced rCCO. The femoral beta angle, assessing the angulation of the distal femur, was not observed to affect the occurrence of rCCO or aCCO. The femoral angles used in this study were described previously; alpha and gamma angles are used in the assessment of the angulation of the proximal femur and the beta angle refers to the angulation of the distal femur. Furthermore, gamma angle, sometimes referred to as an angle of inclination, has been described as having a direct effect on the health status of the hip joint (Tomlinson et al. 2007). It can be concluded that beta angle, as a criterion for assessment of the stifle joint and distal femur, has no effect on the development of the CCO located proximally on the femur. Therefore, it can be concluded that the CCO develops in association with femoral neck angulation, and may be considered as an adaptation to the forces acting through the femoral neck created by the body weight. This is further supported by our finding that both the rCCO and the aCCO were observed to be associated with the weight of the dog. We observed that heavier dogs were more likely to have a more pronounced CCO. In addition to the distraction index and subluxation, which have been described as predisposing factors in the development of hip dysplasia (Smith et al. 1993; Smith et al. 1996; Mayhew et al. 2002), the CCO phenotype can predict the possible development of hip dysplasia if environmental factors such as weight are in play. It has been suggested that a large angle of inclination of the femoral neck indicates an increased likelihood of developing osteoarthritis changes in the hip joint (Tomlinson et al. 2007). This is, however, not in agreement with the findings based on the alpha and gamma angle. These are affected by the inclination angle of the femoral neck and only a large alpha angle leads to more pronounced CCO. In fact, gamma angle, or the angle of inclination, has recently been reported not to be predictive in hip dysplasia development (Sarierler 2004).

We observed a high prevalence of aCCO on the proximal femur (n = 96), which was similar to that described in the study conducted by Ackerman (1982) who reported that the presence of CCO on cadaveric bone was a more visible feature of the femoral neck compared with radiographs. Furthermore, our study also revealed no association between the aCCO observed directly on the cadaveric bone and the rCCO observed on the radiographs. This finding may be attributed to the fact that the aCCO could be quantified using callipers, which was not possible when assessing the rCCO on the radiographs. Therefore, the assessment of the rCCO was subjective and an analysis of intra- and inter-observer variability would be required to assess its true diagnostic value. This finding is in agreement with other studies of Kishimoto et al. (2010) and Powers and co-workers (2004) who described radiography as a less sensitive method for the visualisation of CCO compared with other methods. This can be explained in several ways. First, the presence of severe osteoarthritis changes on the femoral head and neck may obscure the presence of the CCO (Powers et al. 2004). Second, the positioning of the femur and pelvis has been reported to strongly affect the visibility of the CCO particularly in small CCOs (Morgan 1987; Kishimoto et al. 2010). Third, its visibility is affected by the degree of calcification of the subchondral bone. Therefore, it is possible that following the formation of a prominence above the surface of the bone or cartilage surface, the subchondral bone calcifies. It has been reported that computed tomography scans (Kishimoto et al. 2010) or arthroscopy (Powers at al. 2004) are superior to radiography in discerning the presence of CCO in the hip joint.

Caudolateral curvilinear osteophytes are associated with the degree of angulation of the proximal femur and with the weight of the dog. CCOs are less pronounced when the femur is straight and more pronounced with increased weight. CCOs might be considered as being associated with osteoarthritis, but in themselves, they should be considered as an adaptation to femoral angles and weight rather than as osteophytes.

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Received: January 4, 2016
Accepted after corrections: April 15, 2017