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Research Article

Radiographic Morphometry of the Feline Hip Joint: Clinical Associations and Reference Benchmarks

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Abstract

Interest in feline orthopedic diseases has increased in recent years, highlighting the need for standardized radiographic criteria for diagnosing hip dysplasia in cats, similar to those used in dogs. This prospective study investigated associations between morphometric parameters and radiographic hip scores in 56 client-owned cats. Standard ventrodorsal pelvic radiographs were obtained, and the Norberg angle (NA) and femoral inclination angle (FIA) were measured bilaterally. Hips were scored using an adapted BVA/KC hip score scheme, with NA analyzed separately and secondary changes categorized. Group differences were analyzed with t-tests/ANOVA or Mann-Whitney U/Kruskal-Wallis as appropriate (Bonferroni where applicable); associations used Spearman's ρ; predictors were modeled with multiple linear regression. In non-lame cats, NA values were 91.46±6.80° (right) and 92.55±6.90° (left), while FIA values were 121.71±5.57° (right) and 124.83±5.81° (left). Lame cats had significantly lower NA and higher FIA than non-lame cats, along with higher primary change and total scores. NA correlated negatively with primary and secondary change scores, secondary change categories (SCcat), and total scores, whereas FIA correlated positively. Across SCcat, NA decreased and primary change scores increased with severity. Younger cats showed higher NA values, while sex and fertility status had secondary effects. In multivariable models, NA was a negative predictor and FIA a positive predictor of total scores bilaterally. These results demonstrate that decreased NA and increased FIA are strongly associated with radiographic osteoarthritic changes, underscoring the role of hip geometry in the pathogenesis of feline hip dysplasia and osteoarthritis.

Keywords: Cats, Hip dysplasia, Lameness, Orthopedics, Radiography

Introduction

Hip dysplasia (HD) is a developmental disorder of the coxofemoral joint characterized by laxity, incongruity between the femoral head and acetabulum, subluxation, and subsequent degenerative changes [1-3]. Although extensively studied in dogs, feline HD has received comparatively limited attention, yet reports indicate that it is more common than previously assumed [1,4]. Breed-dependent variation is evident, with purebred cats such as Maine Coons and Scottish Folds showing higher susceptibility than domestic shorthairs [1,5,6]. Similar to other species, feline HD is considered heritable with a polygenic mode of inheritance [1,4,6]. However, in contrast to dogs, large-scale screening or breeding programs in cats are less frequently reported, and available epidemiological data provide insight into disease distribution [1,7].

Radiography remains the gold standard for diagnosing and phenotypically evaluating HD [2,8,9]. Standard ventrodorsal pelvic radiographs are routinely employed to assess joint congruity and acetabular coverage of the femoral head [2,5,6]. Yet, direct application of canine diagnostic thresholds to cats is problematic due to anatomical differences. Cats possess shallower acetabula, meaning the canine benchmark of >50% femoral head coverage may lead to false-positive diagnoses of dysplasia [2,5,6,9]. The Norberg angle (NA) is a key radiographic parameter for evaluating hip congruity and reported reference values in cats vary across studies. Small-scale studies have reported NA values between ~92° and 99° in clinically healthy cats, with lower values in dysplastic or osteoarthritic individuals [10-12]. However, these studies differed in sample size, breed composition, and age distribution, emphasizing the importance of reporting reference values across defined populations.

Another morphometric parameter of biomechanical importance is the femoral inclination angle (FIA), defined by the orientation of the femoral neck relative to the shaft. Deviations in FIA alter joint loading patterns and may predispose to subluxation, luxation, or degenerative joint disease [13-16]. Although well defined in canine orthopedics, considering that reference ranges or their relationship with HD have been reported in only a few studies in cats [17,18], it is thought that more research is needed in this area. Establishing reliable feline-specific values for both NA and FIA are therefore clinically relevant for diagnosis, prognosis, and surgical planning.

In canine medicine, the British Veterinary Association/ Kennel Club (BVA/KC) hip scoring system is widely applied to evaluate radiographic features of hip dysplasia and secondary osteoarthritic changes, providing a structured and semi-quantitative assessment of hip joint morphology [19]. Although feline-specific hip scoring systems are still under development, adaptation of established canine schemes offers a pragmatic approach to standardize radiographic assessment of feline hip joints. However, ongoing efforts to establish species-specific consensus cut-off values and reference ranges underscore the importance of continued research in cats.

The present study aimed to (1) investigate associations between morphometric parameters (NA and FIA) and radiographic dysplasia scores in cats, (2) evaluate the influence of demographic factors (age, sex, neuter status, and breed), and (3) generate reference data for feline hips using an adapted BVA/KC scoring system. By independently analyzing the Norberg angle and integrating osteoarthritic features through secondary change classification, this study provides new insights into feline-specific diagnostic markers of HD and contributes reference values that may improve both clinical evaluation and breeding strategies. We hypothesized that lower NA and higher FIA would be associated with greater radiographic hip scores, and that demographic factors and secondary change categories would further influence these associations.

Material and Methods

Ethical Statement

This study was approved by the Aydin Adnan Menderes University Animal Experiments Local Ethics Committee (Approval no: 64583101/2025/134 on 14.08.2025). Owners provided informed consent prior to participation.

Animals

This prospective study enrolled 56 client-owned cats of various breeds, ages, and sexes, presented to the Research and Practice Animal Hospital, Faculty of Veterinary Medicine, Aydin Adnan Menderes University. Cats of any breed, sex, and neuter status were eligible if they had no other orthopedic disorders of the skeletal system, aside from confirmed or suspected HD. Accordingly, the study population included both clinically non-lame cats and cats exhibiting hindlimb lameness attributable to hip pathology. Cats were excluded entirely from the study if they had a history of pelvic or femoral fractures (including the acetabulum, femoral head, or femoral neck), major trauma, or were younger than 1 year of age. Cats under 1 year of age were excluded because incomplete skeletal maturity may affect hip joint morphology and radiographic measurements, potentially confounding the assessment of HD-related changes. Cats exhibiting lameness not attributable to the hindlimbs or hip joints (e.g., forelimb lameness or neurologic causes) were also excluded to ensure that any observed locomotor impairment could be reliably associated with hip pathology. For each enrolled cat, demographic data including age, breed, sex, and reproductive status were recorded. Age was categorized by rounding to the nearest whole year.

Clinical and Orthopedic Examination

All cats underwent a comprehensive physical and orthopedic examination performed by the same surgeon (Y.A.O.). General examinations included history, inspection, palpation, percussion, and auscultation. Orthopedic assessment focused on lameness, supplemented by the supination-pronation test, biceps traction test, cranial drawer motion, tibial compression test, and Ortolani maneuver.

Radiographic Imaging, Morphometric Measurements and Hip Scoring

Cats eligible for inclusion in the study underwent ventrodorsal pelvic radiography. Radiographs were obtained without general anesthesia or sedation, using gentle manual restraint performed by experienced personnel. Positioning was achieved with the hindlimbs extended caudally and the patellae centered to obtain acceptable pelvic symmetry. Sedation was not routinely used in order to minimize pharmacological intervention in client-owned cats, largely due to owner preference or refusal of sedation or anesthesia for diagnostic radiography alone, and because satisfactory positioning could be achieved through gentle manual restraint in the majority of cases. When initial images showed suboptimal positioning or technical imperfections (e.g., pelvic rotation or limb asymmetry), additional radiographs were obtained during the same session to achieve diagnostically acceptable images. Radiographs that remained inadequate despite repositioning were excluded from analysis. No averaging of measurements across multiple radiographic exposures was performed; instead, only the final image meeting predefined quality criteria was included for morphometric and scoring analyses. Digital evaluation (Animalcare, Mindray, Shenzhen, China) and software (Geogebra, Linz, Austria) were used to measure the NA and FIA bilaterally. The NA was defined as the angle formed by a line connecting the centers of both femoral heads and a line from the femoral head center to the craniolateral acetabular rim *(Fig. 1-a)*. The FIA was measured using the SYMAX method, as the angle between the femoral neck axis and the femoral shaft axis *(Fig. 1-b)* [8,20]. Each measurement was repeated twice by the same observer, and the mean of the two measurements was used for analysis. Radiographs with inadequate positioning or technical errors were excluded.

Hip joints were evaluated using the British Veterinary Association/Kennel Club (BVA/KC) hip scoring system [19], originally developed for dogs but adapted for feline use. The seven designated anatomical sites (subluxation, cranial acetabular edge, dorsal acetabular edge, cranial effective acetabular rim, acetabular fossa, caudal acetabular edge, femoral head and neck exostoses, and femoral head recontouring) were scored according to the scheme. In this study, the Norberg angle was excluded from the cumulative score and analyzed independently due to the absence of established feline reference ranges and the aim of evaluating its diagnostic role separately. Thus, each hip was scored out of 47 points, yielding a bilateral maximum of 94.

For each hip, primary change (subluxation) and secondary changes (degenerative alterations) were scored and combined to generate total hip scores for right and left hips and cumulatively. To allow categorical assessment of osteoarthritic severity, secondary changes were further stratified into the SCcat. Thresholds were pragmatically defined based on the observed distribution of scores and scaled with reference to the canine BVA scheme: none/minimal (0-5), mild (6-10), moderate (11-15), and severe (≥16). SCcat categories were used in correlation and group comparison analyses.

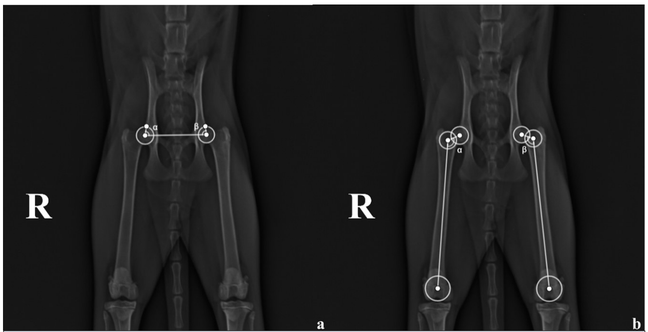

Fig 1. Radiographic measurement of the NA and FIA in cats. (a) NA measurement. The centers of the right and left femoral heads were identified by manually placing circular markers using measurement software. A reference line connecting the centers of both femoral heads and a second line extending from each femoral head center to the corresponding craniolateral acetabular rim were manually drawn. The Norberg angles were automatically calculated by the software and are displayed as α (*right hip*) and β (*left hip*); (b) FIA measurement. The FIA was measured using the SYMAX method. The femoral neck axis and femoral shaft axis were manually defined on the same radiograph, after which the software automatically calculated the angles, displayed as α (*right femur*) and β (*left femur*). Circular markers and reference lines indicate operator-defined anatomical reference points and axes

Statistical Analysis

All statistical analyses were performed using IBM SPSS Statistics version 25.0 (IBM Corp., Armonk, NY, USA). Data were first transferred into Microsoft Excel® (Microsoft Corp., Redmond, WA, USA) for recording and preprocessing. The distribution of continuous variables was assessed using the Shapiro-Wilk test, complemented by visual inspection of histograms and Q-Q plots. Descriptive statistics were expressed as mean±standard deviation (SD) for normally distributed variables and as median with minimum-maximum values for non-normally distributed variables. Categorical variables were summarized as frequencies and percentages.

Lameness status was classified as "lame" or "not lame" and included as a grouping variable in subsequent analyses. Comparisons between right and left hips were conducted using paired-samples t-tests for normally distributed parameters and Wilcoxon signed-rank tests otherwise. Group comparisons according to sex, neuter status, and lameness were carried out with independent-samples t-tests or Mann-Whitney U tests, while differences across age groups, breeds, and SCcat categories were assessed with one-way ANOVA or Kruskal-Wallis tests, followed by Bonferroni-adjusted post hoc tests where appropriate. Associations between morphometric measures (NA and FIA) and radiographic scores (primary and secondary change scores, total score, SCcat) were evaluated using Spearman's correlation coefficients.

Multiple linear regression analyses were used to identify predictors of right and left total hip scores. Independent variables entered into the models included age, sex, neuter status, NA, FIA, and breed, with tabby cats set as the reference category in dummy coding. Although hip scores were not normally distributed, regression analyses were retained because assumptions apply to model residuals rather than raw outcomes. Residual plots confirmed approximate normality and homoscedasticity. Multicollinearity was assessed via tolerance and variance inflation factor (VIF) values (<10), and model robustness was further evaluated with Cook's distance and leverage statistics to rule out influential outliers. A P-value of <0.05 was considered statistically significant for all analyses.

Results

Association of Lameness with Hip Morphometric Parameters and Hip Scores

Table 1 presents the comparison of hip morphometric variables and hip scores between lame and non-lame cats. On both sides, lame cats had statistically significantly lower NA values (P=0.036 and P=0.001 for right and left hips, respectively) and statistically significantly higher FIA values (P=0.006 and P=0.042 for right and left hips, respectively).

Primary change (PC) scores were also statistically significantly higher in lame cats compared with non-lame cats (P=0.048 and P=0.012 for right and left hips, respectively), whereas SC scores did not differ significantly between groups (P>0.05). Furthermore, SCcat classifications and total hip scores for each hip and cumulatively were consistently higher in lame cats (P<0.05; *Table 1*).

Correlation Analyses

Correlation matrices for the right and left hips are presented in *Table 2* and *Table 3*, respectively.

For the right hip *(Table 2)*, the NA was negatively correlated with several hip score components, including PC score, SC score, SCcat, hip score, and the cumulative score (ρ=–0.272 to –0.464, P<0.05; *Table 2*). The FIA was positively correlated with hip score components, with significant associations for PC score, total PC score, the right hip score, and the cumulative score (ρ=0.315–.429, P<0.05). Strong positive associations were observed among hip score components themselves, particularly between PC and SC scores (ρ=0.337, P=0.011) and across total and cumulative scores (ρ=0.671–.875, P<0.001; *Table 2*).

For the left hip *(Table 3)*, the NA showed strong negative correlations with hip score components, including PC score, SC score, SCcat, and total hip score (ρ=–0.675 to –0.530, P<0.001; *Table 3*). The FIA correlated positively with several components, with significant associations for PC score (ρ=0.431, P=0.001), SCcat (ρ=0.274, P=0.041), and the total hip score (ρ=0.305, P=0.022). Strong positive correlations were also observed among hip score components, particularly between PC and SC scores (ρ=0.523, P<0.001) and across total hip scores (ρ=0.761–.918, P<0.001; *Table 3*).

Group Comparisons (Age, Breed, and Demographics)

Age Comparisons: Hip morphometric parameters and hip scores according to age groups are presented in *Table 4*. Both right and left NA values were higher in younger cats compared with older cats (P=0.048 and P=0.011, respectively; *Table 4*). Specifically, cats aged 1-2 years had significantly greater NA values than cats aged 4-6 years *(Table 4)*. The FIA values showed a slight decrease with age, although these differences were not statistically significant (P>0.05). Primary, secondary, and total hip scores did not vary significantly across age groups *(Table 4)*.

Breed Comparisons: Breed-related comparisons of hip morphometric parameters and hip scores are shown in *Table 5*. No significant breed-related differences were detected in NA and FIA values, or hip score components (all P>0.05; *Table 5*). Descriptively, Persian and Scottish

Table 1. *Hip morphometric variables and hip scores according to lameness status (means±SD for angles; medians [min-max] for scores)*

Variables	Hip	Lameness Status: Non-Lame (n=37)	Lameness Status: Lame (n=19)	P-value
NA	Right	91.46±6.80	83.41±9.34	0.036
	Left	92.55±6.90	84.40±8.88	0.001
FIA	Right	121.71±5.57	127.84±4.66	0.006
	Left	124.83±5.81	128.30±5.32	0.042
PC	Right	2 (0-10)	4 (0-11)	0.048
	Left	2 (0-9)	4 (1-8)	0.012
SC	Right	6 (0-15)	7 (1-14)	0.326
	Left	8 (1-18)	10 (4-25)	0.118
SCcat	Right	2 (1-3)	2 (1-4)	0.041
	Left	2 (1-3)	2 (1-4)	0.030
Total	Right	9 (0-23)	11 (5-25)	0.038
	Left	8 (1-23)	12 (4-26)	0.030
Cumulative Score		19 (5-40)	23 (9-42)	0.041

NA: Norberg angle; FIA: Femoral inclination angle; PC: Primary change score, SC: Secondary changes score; SCcat: Categorized secondary change score

Table 2. *Right hip correlation matrix among morphometric measures and hip scores (n=56)*

Variables	1	2	3	4	5	6	7	8	9
1. Right NA		0.016	-0.433**	-0.299*	-0.272*	-0.364**	-0.328*	-0.464**	-0.387**
2. Right FIA			0.330*	0.250	0.211	0.429**	0.228	0.315*	0.338*
3. Right PC				0.337*	0.401**	0.836**	0.315*	0.757**	0.607**
4. Right SC					0.610**	0.329*	0.783**	0.855**	0.642**
5. Right SCcat						0.412**	0.390**	0.520**	0.481**
6. Total PC							0.452**	0.671**	0.783**
7. Total SC								0.710**	0.875**
8. Right Hip Score									0.775**
9. Cumulative Score									

*NA: Norberg angle; FIA: Femoral inclination angle; PC: Primary change score, SC: Secondary changes score; SCcat: Categorized secondary changes. * P<0.05, ** P<0.01, two-tailed*

Table 3. Left hip correlation matrix among morphometric measures and hip scores (n=56)

Variables	1	2	3	4	5	6	7	8	9
1. Left NA		-0.233	-0.675**	-0.562**	-0.546**	-0.590**	-0.441**	-0.645**	-0.530**
2. Left FIA			0.431**	0.210	0.274*	0.405**	0.237	0.305*	0.344**
3. Left PC				0.523**	0.499**	0.795**	0.431**	0.806**	0.693**
4. Left SC					0.688**	0.430**	0.823**	0.918**	0.785**
5. Left SCcat						0.477**	0.612**	0.590**	0.572**
6. Total PC							0.452**	0.654**	0.783**
7. Total SC								0.761**	0.875**
8. Left Total Score									0.862**
9. Cumulative Score									

*NA: Norberg angle; FIA: Femoral inclination angle; PC: Primary change score, SC: Secondary changes score; SCcat: Categorized secondary changes. * P<0.05, ** P<0.01, two-tailed*

Table 4. Hip morphometric measures and hip scores by age groups (means±SD for angles; medians [min-max] for scores)

Variables	Hip	Age (year)						P-value
		1 (n=3)	2 (n=9)	3 (n=13)	4 (n=12)	5 (n=11)	≥6 (n=8)	
NA (°)	Right	95.13±4.22[a]	92.38±5.77[a]	88.27±3.74[a,b]	83.71±11.85[b]	85.4±9.02[b]	85.86±5.71[b]	0.048
	Left	93.7±6.2[a]	94.93±5.75[a]	90.38±5.47[a,b]	84.38±9.18[b]	85.68±10.27[b]	85.35±5.79[b]	0.011
FIA (°)	Right	127.98±3.77	127.34±5.59	125.81±3.77	124.81±4.59	121.2±6.82	125.57±7.03	0.164
	Left	131.66±2.44	128.28±5.6	126.34±4.57	126.22±4.54	123.15±7.56	124.42±6.67	0.186
PC	Right	5 (1-6)	2 (0-7)	4 (0-7)	5 (0-11)	3 (0-10)	4 (1-10)	0.492
	Left	4 (4-9)	3 (0-7)	2 (0-8)	5 (1-9)	2 (0-7)	1.5 (0-4)	0.111
SC	Right	7 (5-12)	7 (1-9)	6 (1-10)	8 (1-15)	6 (0-11)	8 (1-13)	0.667
	Left	7 (5-18)	7 (1-14)	6 (3-14)	13 (2-25)	9 (1-17)	7.5 (3-16)	0.087
SCcat	Right	2 (1-3)	2 (1-2)	2 (1-2)	2 (1-3)	2 (1-3)	2 (1-3)	0.867
	Left	2 (1-3)	2 (1-3)	2 (1-3)	3 (1-4)	2 (1-3)	2 (1-3)	0.118
Total Score	Right	12 (6-18)	9 (4-14)	9 (5-16)	12 (3-25)	10 (0-20)	12 (3-23)	0.403
	Left	9 (9-22)	9 (1-14)	8 (3-19)	16 (2-26)	10 (3-21)	7.5 (4-17)	0.130
Cumulative Score		21 (15-40)	19 (5-28)	18 (9-26)	27 (5-42)	17 (8-37)	21 (7-40)	0.087

NA: Norberg angle; FIA: Femoral inclination angle; PC: Primary changes, SC: Secondary changes; SD: Standard deviation; SCcat: Categorized secondary changes. Different superscript letters (a, b) within a row indicate statistically significant differences between groups

Fold cats tended to have lower NA values, whereas British Shorthair cats showed intermediate values (*Table 5*).

Demographic Factor Comparisons: Comparisons according to sex and fertility status are presented in *Table 6*. Sex-related differences were observed for FIA values, with males showing higher values than females (P=0.013 and P=0.025, respectively). Fertility status was associated with NA values, as sterile cats had statistically significantly higher NA values compared with intact cats (P=0.027 and P=0.033, respectively). Hip score components did not differ significantly between sexes or fertility groups (P>0.05; *Table 6*).

Morphometric Parameters According to SCcat

Morphometric parameters and PC scores according to SCcat categories are summarized in *Table 7*. NA values decreased significantly with increasing severity of secondary changes in both hips, with the lowest values observed in the moderate group (P=0.001 and P=0.041 for left and right hips, respectively). FIA values tended to be higher in the moderate group, but these differences were not statistically significant (P>0.05). PC scores were significantly higher in the moderate group compared with the none and mild groups (P<0.001 and P=0.014 for left and right hips, respectively). Only one left hip was classified as severe, preventing statistical evaluation of this category (*Table 7*).

Regression Analyses

Results of multiple linear regression analyses predicting right and left total hip scores are presented in *Table 8*. For the right hip, the model was statistically significant,

Table 5. *Hip morphometric measures and hip scores by breeds (means±SD for angles; medians [min-max] for scores)*

Variables	Hip	Breed									P-value
		ANK (n=3)	BRI (n=13)	CHI (n=4)	MIX (n=10)	PER (n=3)	CAL (n=4)	SCO (n=10)	SIA (n=2)	TAB (n=7)	
NA (°)	Right	90.10±9.71	87.95±9.61	90.63±6.70	90.13±6.96	82.90±5.16	86.38±5.91	84.52±11.72	90±5.94	85.47±3.42	0.715
	Left	92.17±12.09	89.42±10.73	92.90±6.25	94.51±5.61	93.17±5.48	90.85±6.99	86.12±10.60	87.55±2.47	91.93±7.86	0.648
FIA (°)	Right	124.81±10.77	124.60±4.96	125.19±4.95	124.99±6.52	127.90±3.87	122.77±5.73	127.29±4.73	118.83±7.43	124.40±5.66	0.714
	Left	125.28±8.68	126.27±5.02	126.61±4.04	125.73±7.04	129.5±6.77	123.13±2.78	128.31±4.55	120.51±4.52	124.35±8.17	0.666
PC	Right	5 (0-5)	4 (0-7)	1.5 (0-5)	4 (0-10)	5 (4-8)	3.5 (1-4)	1 (0-11)	3.5 (0-7)	4 (1-10)	0.491
	Left	2 (0-4)	4 (0-9)	2.5 (0-5)	1 (0-9)	2 (1-8)	1.5 (0-5)	3.5 (0-8)	5 (3-7)	2 (0-6)	0.308
SC	Right	1 (0-11)	8 (5-12)	6 (3-9)	3.5 (1-13)	6 (4-10)	6.5 (4-15)	6 (2-14)	4.5 (2-7)	8 (1-10)	0.404
	Left	8 (7-12)	9 (1-18)	7 (1-25)	5.5 (2-16)	8 (3-11)	10 (3-17)	10 (2-14)	9.5 (9-10)	10 (4-15)	0.862
SCcat	Right	1 (1-3)	2 (1-3)	1.5 (1-2)	1 (1-3)	2 (1-2)	2 (1-3)	2 (1-3)	1.5 (1-2)	2 (1-2)	0.360
	Left	2 (2-3)	2 (1-3)	2 (1-4)	1.5 (1-3)	2 (1-3)	2.5 (1-3)	2.5 (1-3)	2 (2-2)	2 (1-3)	0.861
Total Score	Right	6 (0-16)	12 (5-18)	7 (4-14)	6.5 (3-23)	12 (10-15)	9 (7-19)	6 (3-25)	8 (2-14)	12 (5-20)	0.355
	Left	11 (8-12)	10 (3-23)	9 (1-26)	6 (2-17)	8 (4-16)	11.5 (3-21)	12 (2-19)	12 (10-14)	10 (4-17)	0.755
Cumulative Score		17 (8-28)	21 (17-40)	16 (5-40)	14 (7-40)	20 (19-26)	19 (13-40)	18.5 (5-42)	20 (12-28)	22 (12-37)	0.663

__NA:__ Norberg angle; __FIA:__ Femoral inclination angle; __PC:__ Primary changes, __SC:__ Secondary changes; __SD:__ Standard deviation; __SCcat:__ Categorized secondary changes; __ANK:__ Ankara; __BRI:__ British Shorthair; __CHI:__ Chinchilla; __MIX:__ Mix; __PER:__ Persian; __CAL:__ Calico;__O:__ Scottish Fold; __SIA:__ Siamese; __TAB:__ Tabby

Table 6. *Hip morphometric measures and hip scores by demographic factors (sex and fertility status; means±SD for angles; medians [min-max] for scores)*

Variables	Hip	Sex		P-value	Fertility		P-value
		Male (n=27)	Female (n=29)		Sterile (n=29)	Intact (n=27)	
NA (°)	Right	88.24±7.54	86.64±8.83	0.461	89.21±8.98	85.48±6.91	0.027
	Left	91.74±8.63	89.70±8.71	0.371	92.83±6.63	86.89±9.62	0.033
FIA (°)	Right	126.94±5.43	123.24±5.28	0.013	125.26±6.13	124.77±5.13	0.746
	Left	127.80±5.61	124.34±5.64	0.025	125.94±5.76	126.09±6.03	0.923
PC	Right	4 (0-10)	4 (0-11)	0.530	4 (0-10)	4 (0-11)	0.875
	Left	3 (0-9)	2 (0-9)	0.967	2 (0-9)	3 (0-9)	0.862
SC	Right	6 (1-13)	7 (0-15)	0.675	6 (0-11)	6 (0-15)	0.947
	Left	7 (2-18)	9 (1-25)	0.850	10 (1-18)	8 (2-25)	0.850
SCcat	Right	2 (1-3)	2 (1-3)	0.927	2 (1-3)	2 (1-3)	0.820
	Left	2 (1-3)	2 (1-4)	0.965	2 (1-4)	2 (1-3)	0.986
Total Score	Right	9 (3-23)	11 (0-25)	0.411	10 (0-25)	10 (3-20)	0.974
	Left	10 (2-23)	10 (1-26)	0.863	9 (2-26)	10 (1-23)	0.994
Cumulative Score		20 (5-40)	19 (5-42)	0.818	19 (7-42)	22 (5-37)	0.761

__NA:__ Norberg angle; __FIA:__ Femoral inclination angle; __PC:__ Primary changes, __SC:__ Secondary changes; __SD:__ Standard deviation; __SCcat:__ Categorized secondary changes

F(13,42)=4.842, P<0.001, explaining 47.6% of the variance (Adjusted R^2=0.476). Significant predictors were male sex (B=2.466, P=0.035), fertility status (B=−2.517, P=0.049), right NA (B=−0.320, P<0.001), right FIA (B=0.448, P<0.001), and Scottish Fold breed compared with tabby (B=−5.470, P=0.010; *Table 8*).

For the left hip, the model was also significant, F (13,42) =3.524, P=0.001, accounting for 37.4% of the variance (Adjusted R^2=0.374). Significant predictors included fertility status (B=−3.719, P=0.029), left NA (B=−0.495, P<0.001), and left FIA (B=0.330, P<0.001). No breed effects reached significance in this model (*Table 8*).

Discussion

The findings support our hypothesis that morphometric parameters, particularly reduced NA and increased FIA, are closely associated with higher radiographic hip scores, while demographic characteristics and SCcat played a

Table 7. Morphometric parameters and primary changes according to categorized secondary changes (SCcat) in cats (means±SD for angles; medians [min-max] for scores)

Variables	Hip	SCcat				P-value
		None (14/21)	Mild (24/29)	Moderate (17/6)	Severe (1/0)	
NA (°)	Left	94.73±5.30[b]	91.95±5.91[b]	82.91±9.84[a]	104	0.001
	Right	91.88±7.12[b]	87.69±6.03[b]	77.45±13.70[a]	—	0.041
FIA (°)	Left	124.32±5.13	125.10±5.57	128.67±6.32	139.9	0.162
	Right	123.90±5.77	125.01±5.22	128.97±6.16	—	0.210
PC	Left	1 (0-4)[a]	3 (0-7)[a,b]	5 (1-9)[b]	9	<0.001
	Right	2 (0-8)[a]	4 (0-10)[a,b]	5.5 (4-11)[b]	—	0.014

***NA:** Norberg angle; **FIA:** Femoral inclination angle; **PC:** Primary changes, **SD:** Standard deviation; **SCcat:** Categorized secondary changes. Group sizes are presented as left/right hips. Different superscript letters (a, b) within a row indicate statistically significant differences between groups*

Table 8. Multiple linear regression predicting right and left total hip scores from morphometric and demographic variables (n=56)

Model	Predictors	B	SE	β	t	P-value
Right hip	Age	0.085	0.452	0.024	0.19	0.851
	Sex (Male vs. Female)	2.466	1.132	0.238	2.18	0.035
	Fertility (Sterile vs. Intact)	-2.517	1.245	-0.243	-2.02	0.049
	Right NA	-0.320	0.073	-0.501	-4.37	<0.001
	Right FIA	0.448	0.106	0.482	4.21	<0.001
	Breed: Scottish Fold (vs. Tabby)	-5.470	2.030	-0.404	-3.00	0.010
	Other Breeds	NS				
Left hip	Age	0.060	0.582	0.014	0.103	0.919
	Sex (Male vs. Female)	-0.386	1.448	-0.032	-0.267	0.791
	Fertility (Sterile vs. Intact)	-3.719	1.648	-0.310	-2.256	0.029
	Left NA	-0.495	0.097	-0.697	-5.091	<0.001
	Left FIA	0.330	0.144	0.368	4.25	<0.001
	Breeds (vs. Tabby)	NS				

***B:** Unstandardized regression coefficient; **SE:** Standard error of the coefficient; **β:** Standardized regression coefficient; **t:** t-statistic; **NA:** Norberg angle; **FIA:** Femoral inclination angle; **NS:** non-significant*

more modest role. By adapting the BVA/KC scheme and analyzing NA independently of the cumulative score, the present study provides a structured methodological framework for evaluating feline hip morphology. This separation was necessary given the lack of validated feline reference ranges and the inconsistencies in previous studies [6,10-12]. The approach allowed NA to be evaluated as a direct predictor of radiographic change, providing preliminary feline-specific reference data and illustrating the broader challenge of translating canine-based frameworks into feline practice.

Current feline-specific scoring systems remain limited to registry-based schemes. The Orthopedic Foundation for Animals (OFA) and the Swedish PawPeds programme grade hips on broad ordinal scales (0-4) [7,21]. While these systems are valuable for population-level surveillance and selective breeding, their coarse categories risk overlooking subtle morphologic variation. Moreover, their reliability is limited by high observer dependence, with agreement rates often inconsistent -particularly in mid-range grades- highlighting that consensus alone cannot serve as a reliable gold standard [22]. In contrast, the adapted BVA/KC system applied in the present study enabled detailed evaluation of individual anatomical landmarks, including acetabular edges, the acetabular fossa, and femoral head and neck exostoses. This component-based framework offered a more nuanced and continuous assessment of both early and advanced changes, extending beyond the limitations of broad categorical grading. Although extrapolation from canine models requires caution, the findings suggest that a structured, multi-parameter approach can provide more clinically informative insights into feline hip morphology.

The inclusion of hindlimb lameness evaluation strengthened the functional interpretation of morphometric findings.

Cats presenting hindlimb lameness consistently exhibited morphometric deviations, indicating that locomotor impairment is more closely associated with joint incongruity and early degenerative changes than with advanced osteoarthritic remodeling *(Table 1)*. The additional link between SCcat categories, cumulative hip scores, and lameness further supports the clinical relevance of radiographic scoring. Given that systematic evaluations of lameness in relation to feline hip scoring are scarce, these clinical-radiographic links should be confirmed with objective gait measures in larger, prospective cohorts.

In the present study, both the NA and FIA were closely associated with radiographic scoring outcomes *(Table 1, Table 2, Table 3, Table 4, Table 5, Table 6, Table 7,* and *Table 8)*, highlighting their value as quantitative descriptors of hip conformation in cats. These measures provide clinically informative benchmarks for interpreting feline hip morphology [6,11]. Previous reports show wide variation in FIA and alignment values, largely attributable to differing measurement methods [17,18], and some studies did not assess FIA at all [17]. In the present study, the SYMAX method was applied, which has been described as a reliable approach for femoral alignment assessment [8], thereby contributing new comparative data. While FIA has been extensively characterized in canine orthopedics [13-15], evidence in cats remains sparse, and methodological inconsistency limits comparability across studies. From this perspective, our results provide preliminary benchmarks rather than diagnostic thresholds, emphasizing the need for standardized measurement protocols and larger datasets to establish robust feline-specific reference ranges.

In the present study, demographic characteristics appeared to play a secondary role in hip morphology, yet some patterns provide important context. The higher NA values observed in younger cats *(Table 4)* support the concept of age-related loss of hip congruity and mirror earlier findings that hip laxity and degenerative changes accumulate with age [6,7]. Sex-related differences were also noted, with males tending toward higher FIA values than females *(Table 6)*, a pattern that may reflect subtle dimorphic variation in pelvic biomechanics rather than a primary risk factor [18]. Fertility status emerged as a particularly interesting factor: sterilized cats exhibited more favorable NA values compared with intact cats *(Table 6)*. Although the influence of gonadectomy on feline hips has not been systematically examined, studies in both cats and dogs suggest hormonal status may alter musculoskeletal development and risk of orthopedic disease [1,6,7,23,24]. This potential protective association in cats is novel but should be interpreted cautiously until confirmed in larger, controlled studies. Breed-related differences were not statistically significant *(Table 5)*; however, the consistently lower NA in Scottish Folds and their identification as a negative predictor in regression *(Table 8)* align with registry-based data highlighting increased susceptibility in purebred populations, particularly Maine Coons and Scottish Folds [1,4-7].

The SCcat classification was introduced as an analytical tool to facilitate stratified evaluation of secondary radiographic changes in relation to morphometric parameters, rather than as a diagnostic grading system. Cats placed in higher SCcat categories consistently showed lower NA and higher PC scores *(Table 7)*, supporting the internal validity of this pragmatic approach. Although the limited number of severe cases restricted statistical evaluation, the observed trends suggest that SCcat, when combined with morphometric analysis, may help distinguish early alterations from more advanced osteoarthritic remodeling. Compared with existing systems such as the OFA registry [7] and the PawPeds programme [21], which rely on broad categorical grading, SCcat integrates both primary and secondary radiographic features and anchors them to specific anatomical changes [19]. This combined framework may therefore offer a more nuanced and clinically informative method for evaluating hip pathology in cats.

Beyond the identification of predictors, the present study contributes preliminary reference values for feline hip morphometry and radiographic scoring *(Table 1, Table 2, Table 3, Table 4, Table 5, Table 6, Table 7,* and *Table 8)*. Establishing such benchmarks is important, as they provide a framework for distinguishing normal variation from pathological change and for monitoring disease progression or treatment outcomes. Given the scarcity of feline-specific data in the feline orthopedic literature, these values address a notable gap and may serve as a foundation for both clinical decision-making and future research in feline hip evaluation.

Several limitations should be acknowledged. The sample size was limited and derived from a single referral center, with restricted representation of some breeds and very few severe SCcat cases, which may limit generalizability. Importantly, radiographs were obtained without anesthesia or sedation, which represents a methodological limitation. Although this approach reflects routine clinical practice in client-owned cats, ventrodorsal positioning, hindlimb extension, and patellar centralization may vary in non-sedated animals and could systematically influence measurements of the NA and FIA. Sedation or general anesthesia was not routinely employed due to owner preference and the desire to minimize pharmacological intervention in a clinical setting, and because diagnostically acceptable positioning could be achieved in the majority of cases with gentle manual restraint by experienced personnel. Consequently, measured values reflect clinically obtainable radiographs rather than idealized anesthetized positioning, which may increase measurement variability but enhances the applicability of the findings to real-world veterinary practice. In the present study, lameness assessment was based on standardized clinical orthopedic examination performed by a single experienced surgeon and included observation of gait, stance, weight-bearing, and targeted orthopedic tests to localize hindlimb involvement. However, lameness was assessed subjectively, and objective gait analysis techniques such as force-plate analysis or motion capture were not employed. This limitation is common in clinical veterinary settings and should be considered when interpreting associations between lameness status and radiographic findings. Inter- and intra-observer repeatability was not formally assessed, although duplicate measurements from the same radiographs were averaged to reduce random measurement error. Another limitation is the use of the BVA/KC scoring system, which was originally developed for dogs and has not been formally validated for cats, although it provided a structured framework for assessment. Similarly, the SCcat stratification was pragmatically defined based on score distribution and should be interpreted as an exploratory analytical framework, pending validation against clinical outcomes in larger, longitudinal datasets. The multiple linear regression models included several independent variables relative to the sample size, raising the possibility of overparameterization. Although multicollinearity diagnostics and residual analyses did not indicate model instability, these findings should be interpreted cautiously. Future studies with larger sample sizes may benefit from simplified model structures, such as binary breed classification (purebred vs. non-purebred) or penalized regression approaches, to improve model parsimony and robustness. In addition, the referral-based population studied here may not fully reflect the general feline population, potentially introducing selection bias. Finally, the cross-sectional design precludes conclusions regarding disease progression, and functional assessments such as objective gait analysis were not performed. Future studies should therefore include larger, multicenter populations with longitudinal follow-up, incorporate validated feline-specific scoring criteria, and integrate functional outcome measures to refine diagnostic thresholds.

In conclusion, this study demonstrates that the NA is the most reliable radiographic parameter for assessing feline hip dysplasia, showing strong associations with primary and secondary changes, SCcat categories, and total hip scores. Clinically non-lame cats exhibited NA values of 91.46±6.80° (right) and 92.55±6.90° (left), whereas lame cats showed lower NA values (83.41±9.34° right; 84.40±8.88° left), supporting the clinical relevance of reduced acetabular coverage. The FIA also contributed as a supportive predictor, particularly in regression analyses, with non-lame cats showing FIA values of 121.71±5.57° (right) and 124.83±5.81° (left) and lame cats demonstrating higher FIA values (127.84±4.66° right; 128.30±5.32° left). While demographic factors such as sex, fertility status, and breed exerted secondary but noteworthy influences, NA and FIA remained the most clinically informative morphometric measures. By adapting the BVA/KC scoring system and analyzing NA separately, this work provides practical reference benchmarks for feline hip morphometry and radiographic scoring. These benchmarks may aid veterinarians in distinguishing normal variation from clinically significant dysplasia, guide breeding decisions, and support management strategies. Future multicenter and longitudinal studies, integrating functional assessments, are warranted to validate these findings and refine diagnostic thresholds.

Declarations

Availability of Data and Materials: The data that support the findings of this study are available from the corresponding author (Y.A.O.), upon reasonable request.

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References

1. **Low M, Eksell P, Högström K, Olsson U, Audell L, Ohlsson Å:** Demography, heritability and genetic correlation of feline hip dysplasia and response to selection in a health screening programme. *Sci Rep,* 9 (1):17164, 2019. DOI: 10.1038/s41598-019-53904-w
2. **Pinna S, Tassani C, Antonino A, Vezzoni A:** Prevalence of primary radiographic signs of hip dysplasia in dogs. *Animals*, 12 (20):2788, 2022. DOI: 10.3390/ani12202788
3. **Deabold K, Montalbano C, Miscioscia E:** Feline osteoarthritis management. *Vet Clin North Am Small Anim Pract*, 53 (4): 879-896, 2023. DOI: 10.1016/j.cvsm.2023.02.015
4. **Černá P, Timmermans J, Komenda D, Nývltová I, Proks P:** The prevalence of feline hip dysplasia, patellar luxation and lumbosacral transitional vertebrae in pedigree cats in the Czech Republic. *Animals*, 11 (9):2482, 2021. DOI: 10.3390/ani11092482
5. **Keller GG, Reed AL, Lattimer JC, Corley EA:** Hip dysplasia: A feline population study. *Vet Radiol Ultrasound*, 40 (5): 460-464, 1999. DOI:

10.1111/j.1740-8261.1999.tb00375.x

6. **Perry K:** Feline hip dysplasia: A challenge to recognise and treat. *J Feline Med Surg*, 18 (3): 203-218, 2016. DOI: 10.1177/1098612X16631227
7. **Loder RT, Todhunter RJ:** Demographics of hip dysplasia in the Maine Coon cat. *J Feline Med Surg*, 20 (4): 302-307, 2018. DOI: 10.1177/1098612X17705554
8. **Sarıerler M, Güzel N:** Köpeklerde femoral inklinasyon açısının ölçümünde dört farklı yöntemin karşılaştırılması. *Vet Cer Derg,* 9 (3-4): 5-8, 2003.
9. **Phillips KL:** Orthopedic diseases of young and growing dogs and cats. In, Seiler GS, Thrall DE (Eds): Thrall's Textbook of Veterinary Diagnostic Radiology. 8th ed., 365-384, Elsevier, Missouri, 2024.
10. **Koeppel E, Ebner J:** Hip dysplasia in the cat. *Kleintierpraxis,* 35, 281-298, 1990.
11. **Langenbach A, Green P, Giger U, Rhodes H, Gregor TP, LaFond E, Smith G:** Relationship between degenerative joint disease and hip joint laxity by use of distraction index and Norberg angle measurements in a group of cats. *J Am Vet Med Assoc*, 213, 1439-1443, 1998.
12. **Milken VMF:** Estudo radiográfico comparativo da displasia coxofemoral entre gatos da raça persa e sem raça definida. *PhD Thesis*. Universidade Estadual Paulista, Faculdade de Medicina Veterinaria e Zootecnia, 2007.
13. **Montavon P, Hohn R, Olmstead M, Rudy R:** Inclination and anteversion angles of the femoral head and neck in the dog evaluation of a standard method of measurement. *Vet Surg,* 14 (4): 277-282, 1985. DOI: 10.1111/j.1532-950X.1985.tb00883.x
14. **Sarierler M:** Comparison of femoral inclination angle measurements in dysplastic and nondysplastic dogs of different breeds. *Acta Vet Hung*, 52 (2): 245-252, 2004. DOI: 10.1556/AVet.52.2004.2.13
15. **Dismukes DI, Tomlinson JL, Fox DB, Cook JL, Song KJ:** Radiographic measurement of the proximal and distal mechanical joint angles in the canine tibia. *Vet Surg*, 36 (7): 699-704, 2007. DOI: 10.1111/j.1532-950X.2007.00323.x
16. **Aghapour M, Bockstahler B, Vidoni B:** Evaluation of the femoral and tibial alignments in dogs: A systematic review. *Animals*, 11 (6):1804, 2021. DOI: 10.3390/ani11061804
17. **Swanson EA, Tomlinson JL, Dismukes DI, Fox DB:** Measurement of femoral and tibial joint reference angles and pelvic limb alignment in cats. *Vet Surg*, 41 (6): 696-704, 2012. DOI: 10.1111/j.1532-950X.2012.00996.x
18. **Fonseca RL, Lobo-Jr AR, Santana MIS:** Measurements of femoral angles, femur length, and hip width in cat radiographs. *Arq Bras Med Vet Zootec*, 69 (06): 1513-1520, 2017. DOI: 10.1590/1678-4162-9583
19. **Dennis R:** Interpretation and use of BVA/KC hip scores in dogs. *In Pract,* 34 (4): 178-194, 2012. DOI: 10.1136/inp.e2270
20. **Rumph PF, Hathcock JT:** A symmetric axis-based method for measuring the projected femoral angle of inclination in dogs. *Vet Surg,* 19 (5): 328-333, 1990. DOI: 10.1111/j.1532-950x.1990.tb01200.x
21. **PawPeds:** Our health programmes. https://www.pawpeds.com/healthprogrammes/; *Accessed:* 15.08.2025.
22. **Ball E, Uhlhorn M, Eksell P, Olsson U, Ohlsson Å, Low M:** Repeatability of radiographic assessments for feline hip dysplasia suggest consensus scores in radiology are more uncertain than commonly assumed. *Sci Rep*, 12 (1):13916, 2022. DOI: 10.1038/s41598-022-18364-9
23. **Belanger JM, Bellumori TP, Bannasch DL, Famula TR, Oberbauer AM:** Correlation of neuter status and expression of heritable disorders. *Canine Genet Epidemiol,* 4:6, 2017. DOI: 10.1186/s40575-017-0044-6
24. **Kieves NR, Shoben A, Markley AP:** Risk factors for the development of stifle injuries in canine agility athletes. *Front Vet Sci,* 11:1335939, 2024. DOI: 10.3389/fvets.2024.1335939