

# Precision, reproducibility, and clinical usefulness of measuring the Norberg angle by means of computerized image analysis

Frank H. Comhaire, MD, PhD; Ann C. C. Criel, DVM; Christian A. A. Dassy, DVM; Pierre G. J. Guévar, DVM; Frédéric R. Snaps, DVM, PhD

**Objective**—To evaluate the precision, reproducibility, and clinical usefulness of measuring the Norberg angle (NA) by means of a computerized system of image analysis.

**Sample Population**—1,182 consecutive radiographs of hip joints of various breeds of dogs assessed for hip dysplasia and 72 radiographs of hip joints of German Shepherd Dogs.

**Procedures**—Radiographs were assessed by a panel of 4 experts in consensus, and NAs were measured by means of a computerized system. Results of classification of hip dysplasia according to the Fédération Cynologique Internationale (FCI) and NAs were compared within dogs and among breeds.

**Results**—Measurement of the NA by means of image analysis was twice as reproducible as that via calipers. Mean NA of left hip joints was 0.38° higher than that of right hip joints. The NA values accurately discriminated between hip joints of dogs without or with hip dysplasia, provided the values were also expressed as percentile rank based on the cumulative frequency distribution of NAs within the breed, and had good power to discriminate among various FCI classifications of hip joints. Mean NA for each dog breed as calculated by use of the lower of 2 NAs for each dog was highly variable and was moderately correlated with the existence of hip dysplasia ( $r = 0.5$ ).

**Conclusions and Clinical Relevance**—Computer-assisted measurement of the NA was useful in assessing hip joint quality and can be implemented for quality control and standardization of the FCI classification and for international comparisons. (*Am J Vet Res* 2009;70:228–235)

Hip dysplasia affects as many as 40% of dogs of various breeds,<sup>1</sup> but the prevalence within each breed varies.<sup>2</sup> The predisposition for hip dysplasia is heritable,<sup>3,4</sup> increasing the risk of affected dogs developing osteoarthritis (DJD) at a young age.<sup>5,6</sup> Comparison of genetic data from German Shepherd Dogs with severe hip dysplasia with those of dogs without this predisposition revealed single nucleotide polymorphisms in several quantitative trait loci associated with hip dysplasia.<sup>7</sup> The polygenetic transmission of hip dysplasia causes the phenotype to vary in severity along a continuous gradient that resembles a bell curve, extending from inexistent or discrete to severe dysplasia. Even dogs with borderline hip dysplasia have altered joint kinematics,<sup>8</sup> the long-term effects of which are as yet unknown. In the situation of polygenetic heredity, the influence of environmental and external factors is important for the phenotypic expression of traits.<sup>3</sup>

Although excessive joint laxity<sup>5</sup> is considered the major causal mechanism of hip dysplasia, it appears unlikely that testing only this 1 aspect by means of any

## ABBREVIATIONS

AUC	Area under the receiver operating characteristic curve
DJD	Degenerative joint disease
FCI	Fédération Cynologique Internationale
L-NA	Lower of the 2 Norberg angles for both hip joints of the same dog
M-NA	Mean of the 2 Norberg angles for both hip joints of the same dog
NCSA	National Committee for Skeletal Alterations
OFA	Orthopedic Foundation for Animals
ROC	Receiver operating characteristic

particular distraction or stress method<sup>9–12</sup> will generate an unequivocal prediction of the risk of DJD. Whereas the negative and positive predictive values for diagnostic test results and likelihood ratios for predicting DJD are high when results of distraction tests are extreme<sup>13</sup> (clearly in the diseased or undiseased regions), the accuracy of distraction tests is limited in situations in which results are less clear, which is typical of assessments of a substantial proportion of dogs.

The most commonly used descriptive methods for classifying hip dysplasia in dogs are the system applied in the United States and recommended by the OFA,<sup>2</sup> the method implemented by all 86 member countries of the FCI,<sup>14</sup> and the semiquantitative scheme applied by the British Veterinary Association.<sup>15</sup> Interobserver agreement for the FCI method is acceptable, particularly among experienced assessors.<sup>16</sup>

Received February 15, 2008.

Accepted May 14, 2008.

From the Royal Cynological Society Saint Hubert, Albert Giraudlaan, 98, B-1030 Brussels, Belgium (Comhaire); and the Belgian National Committee for Skeletal Alterations, Albert Giraudlaan, 98, B-1030 Brussels, Belgium (Criel, Dassy, Guévar, Snaps).

The authors thank Dr. Bernd Telhelm for technical assistance and Frank Schoonjans for statistical assistance.

Address correspondence to Dr. Comhaire.

A quantitative method of assessing hips for dysplasia involves measuring the angle formed by the line that connects the centers of each femoral head and the line that connects the center of the femoral head with the cranial aspect of the acetabular rim.<sup>17</sup> The so-called NA is commonly considered a measure of laxity, and it may vary among dogs of the same breed and also between breeds.

The purpose of the study reported here was to evaluate the precision, reproducibility, and clinical usefulness of measuring the NA in dogs by means of a commercially available, computerized system of image analysis. Taking an evidence-based approach, we specifically sought to determine the precision and reproducibility of the NA as determined via the computerized system, whether values of the NA differ between hip joints in the same dog, whether the lower or the mean of the NA for each hip joint should be used for hip joint classification, whether there is a difference in the cumulative frequency distribution of NA among breeds, and whether the mean NA for a breed is related to the prevalence of hip dysplasia in that breed. In addition, we also sought to investigate the accuracy of the NA in discriminating among hip joints of various FCI classifications, whether the NA for a given hip joint is related to the FCI classification for the same hip joint, whether the NA can be used to compare hip joint status in dogs of a particular breed in various countries, and whether the NA can be used to compare accuracy of those who assess radiographs for hip dysplasia.

## Materials and Methods

**Sample population**—Over a period of 14 months beginning June 1, 2006, radiographs of hip joints of dogs, which satisfied the technical requirements of the FCI, were assessed for hip dysplasia. Evaluation of hip joint status is mandatory for 26 breeds of dogs in Belgium, and all radiographs of dogs of these breeds must be assessed by the NCSA. For other breeds, evaluation for hip dysplasia is voluntary.

Mean  $\pm$  SD age of the dogs at the time of radiography was 23.8  $\pm$  10.9 months (geometric mean, 21.9 months; median, 21 months; and range, 13 to 55 months). All radiographs were obtained while dogs were sufficiently sedated to completely relax their muscles.<sup>18,19</sup> Radiographs were sent to the offices of the Royal Cynological Society Saint Hubert, where information regarding the subjects was made anonymous, and the radiographs were scanned to produce electronic images.

Scanned radiographic images were electronically transmitted to the 4 members of the NCSA and to 1 other investigator (FHC), who independently assessed each radiograph. Three members of the committee (ACCC, CAAD, and PGJG) were certified radiologists who work in private veterinary offices, whereas the fourth member (FRS) was a professor of veterinary radiology. During a monthly meeting of the committee, all radiographs received in the preceding month were projected on a screen, and the 4 assessors scored the radiographs with respect to FCI classification of hip dysplasia, coming to a consensus on the final score.

Scoring was based on the descriptive criteria of the FCI,<sup>14</sup> and subclasses A1 and A2, B1 and B2, and C1 and C2 were assigned. Hip joints were characterized as class A when the contact zone between the femoral head and the cranial and dorsal aspects of the acetabulum was extensive; class A2 was assigned when the lateral aspect of the cranial acetabular rim was not fully congruent with the femoral head. Class B was assigned when the zone of contact was less extensive, but coverage of the femoral head was adequate; subclass B2 was used when the lateral aspect of the acetabular rim was not fully congruent. In hip joints characterized as C1, coverage of the femoral head was inadequate, but the femoral head was not subluxated, and there were no signs of arthrosis. When discrete signs of arthrosis were evident, hip joints were characterized as subclass C2. Hip joints were assigned to class D when they were subluxated, when clear signs of DJD without deformation of the femoral head were evident, or both. When arthrotic deformation of the femoral head was evident, hip joints were assigned to class E.

In a second part of our study, radiographs of hip joints were obtained from 72 German Shepherd Dogs consecutively investigated at the Department of Radiology of the Veterinary Faculty of the University of Gießen (Germany) during a 12-month period beginning in June 2006. Four assessors independently assessed these radiographs.

**Measurement of the NA**—In another study,<sup>a</sup> a first series of measurements of the NA was performed by means of the caliper method in 20 dogs (40 hip joints). In the present study, measurements of several metric aspects of hip joints were performed by 1 investigator (FHC) by means of a computer program for image analysis.<sup>b</sup> The computer program has a unique feature that allows for the drawing of a circle that perfectly fits the contour of the femoral head. To do so, the cursor is positioned on the cranial aspect of the border of the femoral head, and the computer mouse is clicked to define a point on the circle. Next, the cursor is moved to the center of the femoral head, during which time the monitor displays a flexible circle defined by the first point and the current cursor position. When the circle has been manipulated so that it fits the contour of the femoral head, the mouse is clicked again. At this point, the circle is fixed, but if necessary, corrections can still be made by moving a point in the center or on the circle until the circle perfectly fits the contour of the femoral head. In order to measure the NA, the cursor is positioned and the mouse is clicked on the following anatomic landmarks, in sequence: the craniolateral aspect of the acetabular rim, the center of the ipsilateral femoral head, and the center of the contralateral femoral head.

**Statistical analysis**—In breeds represented by  $\geq$  14 dogs, weighted means for FCI scores of hip joints each were calculated by attributing 1 point to dogs with FCI class A hip joints, 2 points to dogs with class B hip joints, 3 points to dogs with class C hip joints, 4 points to dogs with class D hip joints, and 5 points to dogs with class E hip joints.<sup>20</sup> These weighted means are unitless values expressing the overall quality of the hip joint status of a particular breed, based on the FCI scor-

ing method. A lower value corresponds to better overall hip joint quality, and higher values indicate poorer hip joint quality.

Mean  $\pm$  SD values of NAs were calculated for each breed. Data on breed and results of the NA measurements were analyzed by use of statistical software.<sup>21,c</sup> Statistics calculated included mean and SD, median and 5th and 95th confidence intervals, and percentile ranking. A Student *t* test was used to compare results obtained in various breeds.

Standard ROC curves<sup>22</sup> were prepared to evaluate the accuracy and criterion values for discriminating among dogs with various classes of hip joints by means of L-NAs or M-NAs. An ROC curve can be constructed to indicate the ability of a particular diagnostic test (eg, use of the NA to classify hip joints) to discriminate between 2 groups (eg, class A hip joints vs class B and C hip joints combined). The AUC is then calculated. The larger the AUC, the greater the power of the diagnostic test to discriminate between the 2 groups. If the test is unable to discriminate between the 2 groups, the ROC curve will consist of a diagonal line and the AUC will be 0.5, whereas a test that perfectly discriminates will result in an AUC of 1.0. A criterion value is generated during construction of the ROC curve, representing the value at which 2 groups are best discriminated. If the NA for a particular hip joint is higher than the criterion value, the hip joint likely belongs to a certain category (eg, class A), and if the NA is lower than the criterion value, the hip joint likely belongs to a different category (eg, classes B and C combined). Predictive values of positive and negative test results were calculated for each criterion value, as were likelihood ratios whereby the ratio of dogs in the positive and the negative groups reflects the prevalence of the disease. Prevalence of hip dysplasia by breed was determined from reports of the OFA.<sup>2</sup>

Bland-Altman plots were prepared to evaluate the reproducibility of measurements performed in duplicate on several hip joints.<sup>23</sup> This statistical method plots the difference between the 2 measurements of the same hip joint on the y-axis in relation to the mean of the 2 measurements on the x-axis. Pearson and Spearman correlation coefficients were calculated to compare NA with the prevalence of hip dysplasia, taking into consideration the distribution of the data. A  $\chi^2$  test was used to evaluate differences in results of hip joint assessments among assessors in the second part of the study.

## Results

Over the study period, 1,182 radiographs of hip joints of dogs satisfied the technical requirements of the FCI and were included. Thirteen percent of radiographs were obtained from dogs of breeds for which evaluation for hip dysplasia was voluntary.

**Precision of measurement of the NA**—The precision of measurement of the NA was strongly influenced by the exact positioning of the center of the circle that surrounded the contour of the femoral head. For example, medial displacement of the center of the femoral head by 3% of the diameter of the head resulted in a 3.4° increase in the NA. A lateral displacement of the

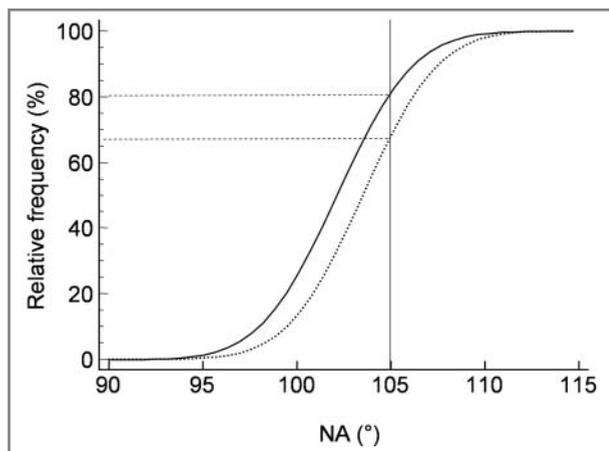


Figure 1—Cumulative frequency distribution of M-NA (dotted curve) and L-NA (solid curve) in 129 German Shepherd Dogs. The horizontal axis represents the NA (in degrees), the vertical axis indicates the cumulative frequency. The dashed vertical line indicates an NA of 105°, which is the value the FCI uses to signify class A (ideal quality) hip joints. Percentages of dogs above the intersection of this vertical line with the cumulative frequency distribution curves (as indicated by the dashed horizontal lines) correspond to proportions of dogs with an NA  $\geq$  105° and that consequently have hip joints suitable for designation as class A.

center of the femoral head by 2% of the diameter of the head resulted in a 1.2° decrease in the NA. The precise positioning of the center of the femoral head was more difficult to achieve by means of conventional calipers than by means of the image analysis software.

**Reproducibility of NA measurement**—Measurement of the NA by means of calipers resulted in an SD of the difference between 2 consecutive measurements that was equivalent to 4% of the mean of the 2 measurements. When the measurement of the NA in the same radiographs was performed by use of computer-assisted image analysis in the present study, the SD of the difference between consecutive measurements was 2%, which was significantly ( $P < 0.001$ ) different from the SD for the NAs measured by means of calipers. Computer-assisted measurements of hip joints of a series of 30 other dogs were also performed by 1 investigator (FHC). In that series, the SD of the difference between the 2 measurements was 1.7%, which was not significantly ( $P = 0.26$ ) different from the SD of 2.0%.

**Comparison of the NA between hip joints**—There was a significant ( $P < 0.001$ ), positive ( $r = 0.74$ ) correlation between NAs of left and right hip joints of the same dog, but the NA of left hip joints was significantly ( $P = 0.002$ ) higher than that of the right hip joints (mean difference, 0.38°). This difference was not attributable to methodologic factors because it persisted when the sequence of measuring the left and right sides was inverted, when both hip joints were measured independently, or when the image was switched around the horizontal axis. A Bland-Altman plot in which the difference between the NAs of 2 hip joints of the same dog was plotted on the y-axis and the mean of the 2 NAs was plotted on the x-axis revealed that the SD of the difference between the NA of the left versus right

hip joint was 3.77°, which corresponded to 3.67% of the mean NA for both sides.

**Influence of using the mean or the lowest of the NAs on the FCI class and the relation between NA and class of hip dysplasia**—To assess the potential influence of using M-NA versus L-NAs in the same dog to designate the class of hip dysplasia, we calculated the percentage of dogs in which hip joints would be designated as class A when each of the methods was used. Frequency distribution curves were plotted for all dogs in the study, revealing that percentages of dogs with an NA  $\geq 105^\circ$  were 48% and 37% for M-NA and L-NA, respectively, for all dogs, and 34% and 20%, respectively, for German Shepherd Dogs only (Figure 1). This meant that 30% to 70% more dogs would be classified as having class A hip joints if the M-NA was used instead of the L-NA.

Table 1—Distribution of hip joint classes and mean and SD of L-NAs of 1,182 dogs evaluated for hip dysplasia in accordance with the modified FCI scoring method.

FCI class	No. of dogs	Percentage of dogs	Mean L-NA (°)	SD (°)
A1	150	12.69	107.00	3.66
A2	411	34.77	106.00	3.42
B1	143	12.09	103.68	4.02
B2	253	21.40	102.60	3.49
C1	133	11.25	98.96	4.67
C2	32	2.71	100.74	5.56
D	53	4.48	94.74	7.51
E	7	0.59	84.33	7.06

All differences between classes are significant ( $P < 0.005$ ), except for the difference between C1 and C2.

Analysis of ROC curves revealed that, for curves in which data for all dogs were included, the AUCs for L-NAs (0.771) and M-NAs (0.765) were similar, but criterion values for L-NAs (103.0°) and M-NAs (104.6°) were different. Curves constructed from data regarding only the hip joints of German Shepherd Dogs revealed AUCs of 0.839 and 0.844 and criterion values of 103.0°

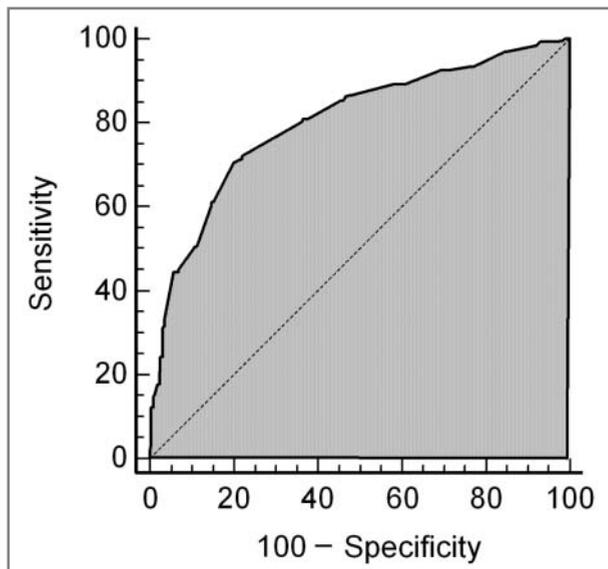


Figure 2—Receiver operating characteristic curve of the L-NAs of 561 dogs with class A hip joints versus dogs with hip joints of all other classes (B, C, D, and E combined). The AUC is 0.785, and the criterion value is 103°, which represents the NA at which the 2 groups of dogs are best discriminated.

Table 2—Values of L-NAs of hip joints in various breeds of dogs evaluated for hip dysplasia, ranked in order from highest to lowest prevalence of dogs with hip dysplasia by breed as reported by the OFA.<sup>2</sup>

Breed	No. of dogs	Prevalence of dogs with hip dysplasia (%)	Mean L-NA (°)	5th percentile L-NA (°)	95th percentile L-NA (°)
Newfoundland	26	25.5	101.8	82.8	111.2
Golden Retriever	103	20.1	101.1	90.9	108.3
German Shepherd Dog	158	19.1	102.5	96.0	108.6
Bernese Mountain Dog	49	16.4	104.8	98.9	110.0
Bouvier des Flandres	18	15.3	103.8	95.6	109.0
Briard	26	14.7	102.9	88.4	109.2
Beauceron	14	14.3	100.8	91.4	111.2
Leonberger	37	14.1	105.2	95.7	113.0
Chinese Shar-Pei	33	13.5	104.4	87.3	111.7
Tibetan Mastiff	14	12.9	104.5	97.2	111.4
Irish Setter	15	12.3	103.0	100.0	107.5
Labrador Retriever	107	12.2	103.4	96.4	110.2
Danish dog	14	12.0	102.7	96.4	109.0
Border Collie	92	11.1	101.7	95.1	106.0
Great Pyrenees	15	9.1	103.5	95.0	110.5
Weimeraner	19	8.7	104.3	95.5	111.1
Vizsla	16	7.2	101.1	96.3	106.0
Doberman Pinscher	30	6.1	107.4	103.0	112.0
Australian Shepherd	20	5.8	101.8	94.5	108.5
Tibetan Terrier	17	6.0	103.4	98.7	108.7
Belgian Malinois	20	5.8	103.5	98.0	109.5
Rhodesian Ridgeback	14	5.2	107.3	103.0	114.2
Flat-Coated Retriever	22	4.4	108.9	99.8	114.0
Belgian Tervuren	15	3.6	105.1	99.9	109.8
Spanish Water Dog*	16	—	102.5	97.3	108.7

\*Not included in the OFA statistics. — = Not available.

and 104.5° for L-NAs and M-NAs, respectively. Curves constructed from data regarding only the hip joints of Golden Retrievers had AUCs of 0.711 and 0.688 and criterion values of 103.0° and 103.2° for L-NAs and M-NAs, respectively. With the exception of the subclasses C1 and C2, differences among all classes of hip joints with respect to L-NA were highly significant ( $P < 0.005$ ), with the highest value in class A1 hip joints and the lowest value in class E hip joints (Table 1).

The AUC for the ROC depicting the accuracy of L-NAs in discriminating between class A hip joints and all other classes of hip joints combined was 0.785, and the criterion value was 103.0° (Figure 2). The predictive value of a negative test result (class A hip dysplasia) was 64.4%, and the associated likelihood ratio was 0.43; the predictive value of a positive test result (all other classes of hip dysplasia combined) was 81.2%, and the associated likelihood ratio was 3.40. When calculations

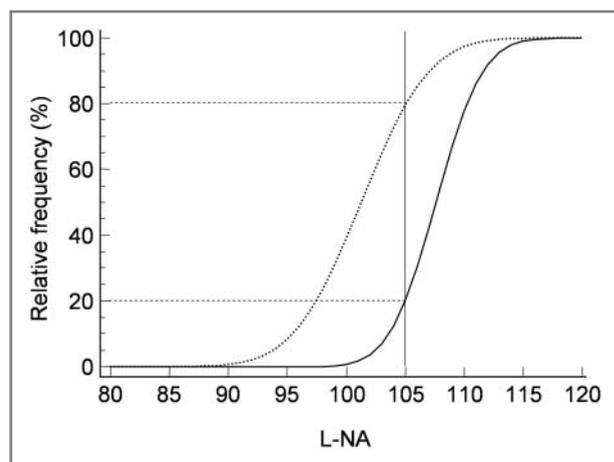


Figure 3—Cumulative frequency distributions of the L-NAs of 92 Border Collies (dotted curve) and 30 Doberman Pinschers (solid curve). By use of these distributions, a particular Border Collie with an L-NA of 105° would be ranked at approximately the 80th percentile of its breed with respect to hip joint quality, whereas a Doberman Pinscher with the L-NA would be ranked at approximately the 20th percentile. Higher percentile ranks correspond to less joint laxity. See Figure 1 for remainder of key.

were restricted to discriminating between class A versus classes B and C combined, similar results were obtained: the AUC was 0.771, the criterion value was 103.0°, and negative and positive likelihood ratios were 0.47 and 3.27, respectively. The AUC for the ROC curve depicting the accuracy of L-NAs in discriminating between dogs without hip dysplasia (classes A and B combined) and dogs with dysplasia (classes C, D, and E combined) was 0.834, and the criterion value was 102.3°. The predictive value of a negative test result (hip dysplasia not evident) was 94.7%, and the associated likelihood ratio was 0.26; the predictive value of a positive test result (hip dysplasia evident) was 38.8%, and the associated likelihood ratio was 2.96.

**Breed differences in NAs**—Calculations of breed differences with respect to NAs were limited to 25 breeds represented by  $\geq 14$  dogs (mean number of dogs by breed, 36; Table 2). The mean L-NA for each breed varied between 100.9° (Beauceron) and 108.9° (Flat-Coated Retriever). Within the Retrievers, there were differences ( $P < 0.01$ ) between breeds. For example, mean L-NAs were 101.1°, 103.4°, and 108.9° for Golden Retrievers, Labrador Retrievers, and Flat-Coated Retrievers, respectively.

Breed differences with respect to NAs were also explored by means of cumulative frequency distributions, from which percentile values could be estimated (Figure 3). Border Collies had, in general, lower NAs than Doberman Pinschers, as suggested by the shift of the frequency distribution curve to the left side of the x-axis.

**Relationship between NA and prevalence of HD by breed**—The highest correlation detected was that between the percentage of dogs with class A hip joints and the weighted mean FCI score ( $r = -0.81$ ;  $P = 0.001$ ). Other significant correlations included those for mean L-NA versus percentage class A hip joints ( $r = -0.48$ ;  $P = 0.02$ ), weighted mean FCI score versus percentage dysplastic hips ( $r = 0.57$ ;  $P = 0.004$ ), mean L-NA versus percentage class A hip joints ( $r = 0.50$ ;  $P = 0.01$ ), and mean L-NA versus weighted mean FCI score ( $r = -0.48$ ;  $P = 0.01$ ).

Table 3—Results of assessments of hip joints of 72 German Shepherd Dogs from Germany, as performed by 4 assessors (W, X, Y, and Z), and 129 German Shepherd Dogs from Belgium, as assessed by the NCSA.

Variable	Assessor W	Assessor X	Assessor Y	Assessor Z	Mean	NCSA
No. of dogs assessed	72	70	72	72		129
Class A (%)	47.2	47.1	33.3	56.9	46.20	35.2
Class B (%)	31.4	28.6	48.6	18.1	31.85	44.0
Class C (%)	14.9	11.4	9.7	15.3	12.53	16.0
Class D (%)	2.8	7.1	4.2	4.2	4.58	3.2
Class E (%)	3.8	5.7	4.2	5.6	4.80	1.6
Breed mean	1.9	2.0	2.0	1.8	1.91	1.9
Classes A and B combined (%)	77.8	75.7	83.1	75.0	77.90	79.2
Ratio A/B	1.59	1.65	0.69	3.15	1.77	0.80
Classes C2, D, and E combined (%)	16.7	21.5	7.0	12.5	14.40	7.90
Area under ROC curve	0.74	0.74	0.85	0.65	0.75	0.86
L-NA criterion value (°)	102	102	104	102	102.5	103
Mean L-NA for class A hip joints (°)	104.91	105.00	105.96	103.95	104.96	104.90
Mean L-NA for class B hip joints (°)	102.22	101.50	102.54	104.08	102.59	101.79
Mean L-NA for class C hip joints (°)	101.10	102.12	99.83	101.45	101.12	99.63
Overall mean L-NA (°)	NA	NA	NA	NA	102.20	102.41

NA = Not applicable.

**Comparison of dogs from 2 countries**—Weighted mean FCI scores were similar ( $P = 0.76$ ) for the 129 German Shepherd Dogs from Belgium and the 72 German Shepherd Dogs from Germany (Table 3). Mean  $\pm$  SD L-NA was  $102.20 \pm 5.66^\circ$  in the dogs from Germany and  $102.41 \pm 4.37^\circ$  in the dogs from Belgium. The cumulative frequency distribution curves for L-NAs in Belgian and German dogs overlapped (not shown).

Some differences regarding the classification of hip joints by use of the FCI system were evident. One assessor more commonly ( $\chi^2 = 8.3$ ;  $P = 0.004$ ) classified hip joints as class A than did the other assessors or the members of the NCSA. Accordingly, the ratio of the number of dogs with class A hip joints to the number of dogs with class B hip joints as designated by that assessor was 2 to 4 times that of the other assessors and members of the NCSA. The mean L-NA for class A hip joints was the same as that of class B hip joints for the aforementioned assessor, and the AUC for the discrimination between these classes was 0.65, indicating poor discriminatory accuracy. Another significant ( $\chi^2 = 5.54$ ;  $P = 0.02$ ) difference was the higher percentage of hip joints that another assessor deemed to have signs of arthrosis (classes C2, D, and E combined), compared with that reported by the other assessors.

## Discussion

The only available method to control hip dysplasia is to prevent dysplastic dogs from breeding; however, in the last 3 decades, this strategy has done little to reduce the prevalence of hip dysplasia.<sup>1,24,25</sup> It has been suggested that selection against hip dysplasia by breeding only non-dysplastic dogs cannot be effective when choice of breedable dogs is based only on phenotypic characteristics and when compliance of breeders with control programs is variable. Other selection criteria are believed to be more important than phenotype.<sup>25</sup> Lack of precision of methods for assessing hip dysplasia that make use of descriptive criteria, such as those used by the OFA and the FCI, also hinders control of hip dysplasia. Specific methods for estimating hip-joint laxity by means of stress or distraction<sup>9-12</sup> and dorsolateral subluxation scores may be better predictors of cartilage damage and DJD.<sup>10,26,27</sup> The NA is another measure of hip joint laxity, and some studies<sup>6,28</sup> have revealed it efficiently predicts the risk of hip dysplasia and DJD in dogs.

Evidently, the accuracy of measurements of NAs will contribute to the power of this method for predicting degenerative hip disease. The relatively poor reproducibility of results by use of the conventional caliper method appears to be attributable to the lack of precision in locating the center of the femoral head. We suggest replacing the conventional caliper method with computer-assisted image analysis because the reproducibility of the computerized method is better and appears to be limited primarily by the sharpness of radiographs used.

Assuming an SD of 2%, an L-NA of  $105^\circ$  (the FCI reference value for dysplasia-free hip joints<sup>14</sup>), and a perfectly Gaussian distribution, the proportion of dogs with class A hip joints and an L-NA  $< 103^\circ$  (ie, the reference value minus 1 SD) should theoretically be 13.7%. The value 12.9% reported here is slightly lower,

which is in agreement with the suggestion that the NA is somewhat skewed toward high values.<sup>13</sup>

Our results indicated that the NA of the left hip joint was slightly greater than that of the right hip joint. A similar finding was reported for a study in which<sup>29</sup> 7,012 conventional radiographs were evaluated, which appeared to support other findings in 286 Portuguese Water Dogs.<sup>30</sup> In the report on Portuguese Water Dogs, the authors stated that the asymmetry of the NA that they detected was highly heritable and could be attributed to variations in quantitative trait loci, which differed between right and left hip joints. In contrast, the authors of the report<sup>29</sup> on conventional radiographs believed that rotation of the pelvis, which was more commonly identified on the left versus right sides of dogs, was responsible for the asymmetry. However, the difference between the NAs of both hip joints is typically small and may be neglected for practical reasons.

Considering the difference between NAs of 2 hip joints of the same dog, the question should be asked whether the lower of the 2 angles or the mean value should be used for designation of FCI class because the FCI suggests a reference value of  $105^\circ$  as a criterion for distinguishing class A hip joints from class B or C hip joints. Also, the FCI states that the worse hip joint should be taken into account when classifying the degree of hip dysplasia.<sup>14</sup> However, in the Netherlands, the sum of the 2 NAs is used, and the same is true for the total score for hip dysplasia suggested by the British Veterinary Association.<sup>15</sup> Other assessors use the L-NA.

If the FCI-recommended reference value of the NA of  $105^\circ$  is used to designate dogs as having class A hip joints, then, according to the results of our study, use of the M-NA will result in a higher percentage of all dogs (and of German Shepherd Dogs) designated as having class A hip joints, compared with the percentage when the L-NA is used. In the present study, the relative difference varied between 30% for all dogs considered together and 70% for German Shepherd Dogs. The M-NA and the L-NA had similar power to discriminate between class A and classes B plus C combined, but the criterion value corresponding with the best discrimination was higher when the M-NA rather than L-NA was used. This was expected because the mean value is always higher than the lower value, except in the uncommon situation in which the NA of both hip joints is identical. Although the criterion value of the L-NA appeared to be the same in various breeds of dogs, this was not the situation when the M-NA was used. Clearly, the mobility of the dogs depends on the functional condition of the hip joint that is most affected. Therefore, and in view of international standardization of hip joint scoring to correspond with the FCI recommendations, the L-NA should be used for classification of hip joints.

In the present study, the L-NA was lower in hip joints of poorer quality, compared with those of higher quality, confirming that more clinically important laxity existed in dysplastic hip joints. This conclusion is logical because joint laxity is considered a major criterion for hip joint scoring. Our findings agree with those of other investigators.<sup>13,28</sup> It is important to notice that

the NAs were significantly different between dogs with hip joints classified as A1 versus A2 and B1 versus B2; this finding underscored the clinical significance and validity of subclassification. No difference in NAs was evident between dogs with class C1 or C2 hip joints because this subclassification is not based on a difference of joint laxity but, rather, on the absence (C1) or the presence (C2) of clinical signs of DJD. Exostotic growth of osteophytes at the craniolateral aspect of the acetabular rim may render measurement of the NA of class D or E hip joints more difficult. Notwithstanding the low number of dogs within these categories, the L-NA was significantly lower in dogs with class E versus class D hip joints, corresponding with a higher degree of hip joint laxity in class E hip joints versus class D hip joints.

Analysis of ROC curves revealed that use of the L-NA to classify hip joints was highly accurate in discriminating among hip joints of various FCI classes and between dogs with versus without hip dysplasia. The AUC of approximately 0.80 associated with the L-NA implied that this measurement is clinically relevant and useful. Negative and positive predictive values as well as likelihood ratios were acceptable to excellent at the selected criterion values.

Major differences in NAs among breeds have been reported<sup>31,32</sup> and reflect the differences in hip joint laxity that can be detected by use of the distraction index.<sup>13</sup> There is a correlation between the NA and the distraction index in dogs.<sup>13</sup> However, the Pennhip method, which makes use of the distraction index, is not accepted for hip joint scoring by the FCI. It appears illogical to use the same reference value of the NA in all breeds of dogs; rather, each dog should be evaluated in relation to others of the same breed. This can be achieved by converting the L-NA to a percentile rank. For example, a Border Collie with an L-NA of 105° would be at the 80th percentile for its breed, whereas a Doberman Pinscher with the same L-NA would be at the 20th percentile for its breed. That Border Collie with an L-NA of 105° would therefore be among the best of its breed with respect to hip joint quality, whereas the Doberman Pinscher with the same L-NA would be among the poorest of its breed. This may have important consequences for when such dogs are used in a program for breed improvement. We suspect that at least some of the confusion concerning the clinical usefulness of the NA relates to the fact that breed differences are typically not properly taken into account. Consequently, we recommend reporting results of NA measurements not only in degrees but also as breed percentile rank. A version of the computer software program<sup>6</sup> used in our study can provide this percentile rank automatically each time a new dog is evaluated.

The relationship between the NA and the probability of DJD has been supported by some investigators<sup>6,27,28</sup> and questioned by others.<sup>12,13,32</sup> In the present study, several markers of hip joint quality by breed were correlated with the probability of hip dysplasia. The highly significant correlation between the percentage of dogs with class A hip joints and the weighted mean FCI score resulted from the fact that the percentage of dogs with a certain class of hip joints was tak-

en into account when calculating the weighted mean FCI score. On the other hand, the strong correlation between the percentage of dysplastic dogs by breed as reported by the OFA and the weighted mean FCI score for dogs from Belgium underscored the validity of both sources of data. It has been claimed that OFA statistics are unreliable because of selection bias.<sup>13</sup> However, the OFA data are in agreement with those obtained for dogs from the United Kingdom that were evaluated by use of the scheme of the British Veterinarian Association<sup>33</sup> and with our results regarding the weighted mean FCI score for dogs from Belgium.

Breeds of dogs with the highest mean L-NA were also those with the highest number of class A hip joints. This was expected because the NA was associated with FCI class. The most interesting finding was, however, that the mean L-NA for each breed was significantly correlated with the percentage of dysplastic dogs as reported by the OFA and the weighted mean FCI score calculated for the dogs from Belgium. This finding emphasizes the clinical usefulness of the NA as a marker of hip joint quality, with a higher NA corresponding to a lower probability of hip dysplasia within a breed.

The precise measurement of the NA can be used as a tool to compare hip joints of particular breeds of dogs from various countries and to control the quality of classifications assigned by various assessors. Results of the comparison of 72 radiographs of hip joints of German Shepherd Dogs from Germany with those of 129 German Shepherd Dogs from Belgium indicated that there was no difference in L-NA by country of origin. Because most German Shepherd Dogs in Belgium originate from the same breeding stock of German ancestors, this finding was expected. The excellent concordance also indicated that selection bias in the submission of radiographs for evaluation was limited, at least among German Shepherd Dogs. Nonetheless, there were remarkable differences as far as the attribution of FCI classes was concerned. Interobserver agreement between experienced assessors is reportedly only fair,<sup>16</sup> which relates to the fact that the criteria applied in the FCI classification system are descriptive rather than objective and quantitative. Measurement of the NA facilitates pinpointing of possible weaknesses in the evaluation technique of particular assessors, such as the incorrect attribution of class A to class B hip joints or the overestimation of signs of DJD. There are good reasons to believe that one of the assessors in our study overestimated the prevalence of degenerative changes because the mean L-NA of dogs with class C2, D, and E hip joints (data not shown) was not different from that of dogs with class B hip joints.

The results of the present study suggested that precise and highly reproducible measurement of the NA can be achieved by means of appropriate image analysis by use of a computer program. The L-NA appeared to be an excellent marker of hip dysplasia, provided that the value was also expressed as percentile rank in relation to a frequency distribution of hip dysplasia within the breed.

a. Coopman F, Comhaire F, Schoonjans F, et al. Hip dysplasia research at Ghent University; towards a new approach to assess

hip quality? (poster presentation). 9th Annu Canine Med Symp Davis, Calif, May 2006.

- b. Digimizer, MedCalc Inc, Mariakerke, Belgium.
- c. Medcalc, MedCalc Inc, Mariakerke, Belgium.

## References

1. Flückiger M, Lang J, Binder H, et al. The control of hip dysplasia in Switzerland. A retrospect of the past 24 years. *Schweiz Arch Tierheilkd* 1995;137:243–250.
2. Orthopedic Foundation for Animals. Hip dysplasia statistics. Available at: [www.offa.org/hipstatbreed.html](http://www.offa.org/hipstatbreed.html). Accessed May 19, 2006.
3. Mäki K, Liinamo A-E, Ojala M. Estimation of genetic parameters for hip and elbow dysplasia in Finnish Rottweilers. *J Anim Sci* 2000;78:1141–1148.
4. Wood JL, Lakhani KH, Rogers K. Heritability and epidemiology of canine hip-dysplasia score and its components in Labrador retrievers in the United Kingdom. *Prev Vet Med* 2002;55:95–108.
5. Henricson B, Norberg I, Olsson SE. On the etiology and pathogenesis of hip dysplasia: a comparative review. *J Small Anim Pract* 1966;7:673–688.
6. Banfield CM, Bartels JE, Hudson JA, et al. A retrospective study of canine hip dysplasia in 116 military working dogs. Part I: angle measurements and orthopedic foundation for animals (OFA) grading. *J Am Anim Hosp Assoc* 1996;32:413–422.
7. Janutta V, Hamman H, Distl O. Complex segregation analysis of canine hip dysplasia in German shepherd dogs. *J Hered* 2006;97:13–20.
8. Bockstahler BA, Henninger W, Müller M, et al. Influence of borderline hip dysplasia on joint kinematics of clinically sound Belgian Shepherd dogs. *Am J Vet Res* 2007;68:271–276.
9. Smith GK, Biery DN, Gregor TP. New concepts of coxofemoral joint stability and the development of a clinical stress-radiographic method for quantitating hip joint laxity in the dog. *J Am Vet Med Assoc* 1990;196:59–70.
10. Flückiger MA, Friedrich GA, Binder H. Correlation between hip joint laxity and subsequent coxarthrosis in dogs. *Zentralbl Veterinarmed [A]* 1998;45:199–207.
11. Ohlerth S, Busato A, Rauch M, et al. Comparison of three distraction methods and conventional radiography for early diagnosis of canine hip dysplasia. *J Small Anim Pract* 2003;44:524–529.
12. Flückiger MA, Friedrich GA, Binder H. A radiographic stress technique for evaluation of coxofemoral joint laxity in dogs. *Vet Surg* 1999;28:1–9.
13. Smith GK, Gregor TP, Rhodes WH, et al. Coxofemoral joint laxity from distraction radiography and its contemporaneous and prospective correlation with laxity, subjective score, and evidence of degenerative joint disease from conventional hip-extended radiography in dogs. *Am J Vet Res* 1993;54:1021–1042.
14. Brass W, Paatsama S. Fédération Cynologique Internationale, scientific committee: hip dysplasia—International Certification, Helsinki, 1983: 1–25. Standards and nomenclature. Available at: [www.fci.be](http://www.fci.be). Accessed Dec 5, 2006.
15. Gibbs C. The BVA/KC scoring scheme for control of hip dysplasia: interpretation of criteria. *Vet Rec* 1997;141:275–284.
16. Verhoeven G, Coopman F, Duchateau L, et al. Interobserver agreement in the diagnosis of canine hip dysplasia using the standard hip-extended radiographic method. *J Small Anim Pract* 2007;48:387–393.
17. Norberg I. Höftledysplasi hos hund. *Nord Med* 1963;69:246.
18. Genevois JP, Chanoit G, Carozzo C, et al. Influence of anaesthesia on canine hip dysplasia score. *J Vet Med A Physiol Pathol Clin Med* 2006;53:415–417.
19. Malm S, Strandberg E, Danell B, et al. Impact of sedation method on the diagnosis of hip and elbow dysplasia in Swedish dogs. *Prev Vet Med* 2006;78:196–209.
20. Beuing R, Erhardt G. Konsequente Anwendung van Zuchtprogramma zur Reduction tierschutzrelevanter Krankheitsdispositionen in der Hundezucht. Available at: [www.hundezucht-aktuell.de/publikation/dvg.html](http://www.hundezucht-aktuell.de/publikation/dvg.html). Accessed Apr 12, 2006.
21. Schoonjans F, Zalata A, Depuydt CE, et al. MedCalc: a new computer program for medical statistics. *Comput Methods Programs Biomed* 1995;48:257–262.
22. Schoonjans F, Depuydt CE, Comhaire F. Presentation of receiver-operating characteristic (ROC) plots. *Clin Chem* 1996;42:986–987.
23. Bland JM, Altman DG. Statistical methods for assessing agreement between two methods of clinical measurement. *Lancet* 1986;1:307–310.
24. Willis MB. A review of the progress in canine hip dysplasia control in Britain. *J Am Vet Med Assoc* 1997;210:1480–1482.
25. Leppänen M, Saloniemi H. Controlling canine hip dysplasia in Finland. *Prev Vet Med* 1999;42:121–131.
26. Lust G, Todhunter RJ, Erb HN, et al. Repeatability of dorsolateral subluxation scores in dogs and correlation with macroscopic appearance of hip osteoarthritis. *Am J Vet Res* 2001;62:1711–1715.
27. Todhunter RJ, Grohn YT, Bliss SP, et al. Evaluation of multiple radiographic predictors of cartilage lesions in the hip joints of eight-month-old dogs. *Am J Vet Res* 2003;64:1472–1478.
28. Adams WM, Dueland RT, Daniels R, et al. Comparison of two palpation, four radiographic and three ultrasound methods for early detection of mild to moderate canine hip dysplasia. *Vet Radiol Ultrasound* 2000;41:484–490.
29. Genevois JP, Cachon T, Fau D, et al. Canine hip dysplasia radiographic screening. Prevalence of rotation of the pelvis along its length axis in 7,012 conventional hip extended radiographs. *Vet Comp Orthop Traumatol* 2007;20:296–298.
30. Chase K, Lawler DF, Adler FR, et al. Bilaterally asymmetric effects of quantitative trait loci (QTLs): QTLs that affect laxity in the right versus left coxofemoral (hip) joints of the dog (*Canis familiaris*). *Am J Med Genet A* 2004;124A:239–247.
31. Tomlinson JL, Johnson JC. Quantification of measurement of femoral head coverage and Norberg angle within and among four breeds of dogs. *Am J Vet Res* 2000;61:1492–1500.
32. Culp WT, Kapatkin AS, Gregor TP, et al. Evaluation of the Norberg angle threshold: a comparison of Norberg angle and distraction index as measures of coxofemoral degenerative joint disease susceptibility in seven breeds of dogs. *Vet Surg* 2006;35:453–459.
33. Comhaire FH, Snaps F. Comparison of two canine registry databases on the prevalence of hip dysplasia by breed and the relationship of dysplasia with body weight and height. *Am J Vet Res* 2008;69:330–333.