Effect of dam and sire qualitative hip conformation scores on progeny hip conformation

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Objective—To determine in dogs what effect using hip conformation scores assigned by the Orthopedic Foundation for Animals (OFA) as a criterion for breeding selections would have on hip conformation scores of the progeny.

Design—Longitudinal study.

Animals—English Setters, Portuguese Water Dogs, Chinese Shar-peis, and Bernese Mountain Dogs for which OFA hip conformation scores were known.

Procedure—Pedigree data were obtained from the national breed clubs and the American Kennel Club and merged with data from the OFA hip conformation score database. An ANOVA was used to evaluate the effects of sex, age at the time of radiographic evaluation, and year of birth on the variation in hip conformation scores among the progeny. Heritability was estimated by use of within-year midparent offspring regression analyses.

Results—Significant differences in progeny hip conformation scores between sexes were not detected, but age at the time of radiographic evaluation and year of birth had a significant effect on hip joint conformation of the progeny. Estimated heritability (mean ± SE) was 0.26 ± 0.03, and dam and sire hip conformation scores had a significant effect on progeny hip conformation scores. Annual decreases in percentage of dysplastic progeny and increases in percentages of progeny and breeding dogs with phenotypically normal hip joint conformation were detected.

Conclusions and Clinical Relevance—Results indicated that hip conformation scores have moderate heritability in dogs and selection of breeding stock with better hip conformation scores will increase the percentage of progeny with phenotypically normal hip joint conformation. (*J Am Vet Med Assoc* 2000; 217:675–680)

Hip dysplasia (HD) in dogs was first described by Schnelle in 1935 and is considered to be one of the major inherited orthopedic problems in dogs.[1,2] In dogs, hip dysplasia has been characterized as a quantitatively inherited trait.[1-5] Quantitatively inherited traits are traits that vary along a continuum from 1 individual to the next and are influenced by > 2 gene pairs and, to various degrees, by environmental factors.[3] The particular hip joint phenotype of any dog is a result of a complex interaction between the dog's genotype and the environment to which it has been exposed.[1-5] Environmental factors that may possibly have an effect on hip joint phenotype include caloric intake, protein intake, calcium intake, growth rate, and amount of exercise.[1-3] High caloric intake, excess protein intake, excess calcium intake, rapid growth rate, and a lack or excess of exercise may result in an increase in severity of HD in dogs. However, in dogs without a genetic predisposition to development of HD, environmental factors alone will not cause the disease.[1-4]

Radiography is currently the most commonly accepted method for large-scale screening of dogs for HD. Unfortunately, currently available radiographic methods do not precisely reflect the genotype of a dog or the risk that that dog will pass on a propensity to develop HD to its offspring.[6] In addition, because some breeders choose not to screen the dogs they breed, breed dogs they know to be dysplastic, or select which dogs to breed on the basis of individual radiographic hip joint phenotype without knowledge of the phenotype of related dogs or previous offspring, the reduction in prevalence of HD in dogs has been slow.[7]

Two studies[4,8] have documented that prevalence of HD in progeny decreases when only radiographically normal dogs are used for breeding; however, to our knowledge, information on the hip conformation scores of the progeny of dogs for which hip conformation scores are known has not been published. The purpose of the study reported here, therefore, was to determine in dogs what effect using hip conformation scores assigned by the **Orthopedic Foundation for Animals (OFA)** as a criterion for breeding selections would have on hip conformation scores of the progeny. The influence of various fixed (ie, sex, age at the time of radiographic evaluation, and year of birth) and random (ie, sire, dam, and sire × dam interaction) effects on the variation in hip conformation scores of the progeny were analyzed. In addition, heritability of hip conformation scores was calculated, and percentage of breeding dogs screened annually and concurrent change in progeny hip conformation scores were analyzed.

Materials and Methods

Data collection—Records of pedigrees of **English Setters (ES)**, **Portuguese Water Dogs (PWD)**, **Chinese Shar-peis (CSP)**, and **Bernese Mountain Dogs (BMD)** in the United States were obtained. All information was provided through direct computerized download or file transfer of each breed's pedigree information. The BMD pedigree information came directly from the **American Kennel Club**

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(**AKC**). The CSP pedigree information came from CSP breeders in the CSP Club of America who maintained their own studbook information. This information was provided prior to AKC breed recognition. Pedigree information from the PWD and ES were provided by conscientious fanciers within the respective breed clubs' health and genetics committees, where extensive pedigree information was recorded and maintained to monitor genetic improvement. Information for these 4 breeds consisted of records of registered animals mated and records of any progeny in a given litter registered through the AKC (BMD) or the breed clubs obtaining pedigree records (ES, CSP, PWD). Pedigree data were representative of animals across all regions of the United States to prevent any biases in the data that could occur by selectively choosing individual breed lines, breeders, or kennels. However, because submission of information was voluntary, number of progeny in the litter was not known for all litters, and therefore, the number of progeny for which hip conformation scores were not available could not be determined. Records for these 4 breeds were chosen because extensive pedigree information could be easily obtained through the cooperation and willingness of conscientious fanciers within these breed clubs. These breeds also had the highest OFA hip radiograph submission rates, allowing a larger number of hip scores in the OFA database to be merged with pedigree registration information, compared with records for other breeds.

Information obtained from the records of the breed clubs included animal identification information, sex, date of birth, sire, and dam. These data were merged with data from the OFA hip conformation score database consisting of animal identification information, sex, age at the time of radiographic evaluation, and hip conformation score. If, for any individual dog, multiple radiographs obtained at different ages had been submitted for evaluation, the score assigned to radiographs obtained at the oldest age was used. Only dogs with hip conformation scores of 1 (excellent), 2 (good), 3 (fair), 5 (mildly dysplastic), 6 (moderately dysplastic), or 7 (severely dysplastic) were included. Dogs with a hip score of 4 (borderline) were not included in the analyses, because this score was considered to be inconclusive. Data for the 4 breeds were analyzed separately.

For dogs < 24 months old at the time of evaluation, the OFA hip score was assigned by a single board-certified veterinary radiologist. For dogs ≥ 24 months old at the time of evaluation, the OFA hip score represented the consensus opinion of 3 board-certified veterinary radiologists. Scores were assigned on the basis of radiographic appearance of the hip joints.[9] Radiologists were given information on the breed, age, and sex of dogs at the time of evaluation so that conformational differences among and within breeds and differences related to degree of skeletal maturity could be taken into account.

Data analysis—An ANOVA was used to evaluate the effects of sex, age at the time of radiographic evaluation, and year of birth on the variation in hip conformation scores among the progeny. Age at the time of radiographic evaluation was classified as ≤ 23 months old, 24 to 35 months old, and ≥ 36 months old. Heritability was estimated by use of within-year midparent offspring regression analyses, using hip conformation scores obtained over a period of 22 (ES), 11 (PWD, CSP), or 19 years (BMD).

To determine whether the sire or the dam had a greater influence on hip conformation scores of the progeny, a categorical models statistical analysis[10] was performed. This analysis evaluates the random effects of sire and dam hip conformation scores, independently and in combination, on the observed variation among progeny hip conformation scores and determines whether a significant interaction exists between the two. Results of the analysis help determine whether gene action is additive or nonadditive. To determine whether hip conformation scores for progeny of parents with various combinations of hip conformation scores were significantly different, a row by column χ^2 analysis was performed, using the percentage of phenotypically normal (hip conformation score of 1, 2, or 3) and dysplastic (hip conformation score of 5, 6, or 7) progeny in each cell.

Linear regression analyses across birth years were performed to calculate annual changes in the percentage of breeding animals for which hip conformation scores were obtained and changes in the percentage of breeding animals with phenotypically normal hip joints. Linear regression analyses were also used to evaluate annual changes across birth years in percentage of progeny that were dysplastic and percentage of progeny that had phenotypically normal hip joints. For all analyses, values of $P < 0.05$ were considered significant.

Results

For all 4 breeds, we did not detect significant differences in progeny hip conformation scores between sexes, and sex accounted for only 0.1 to 0.2% of the variation in progeny hip conformation scores (**Table 1**). Numbers of dogs in each age group category varied considerably among the 4 breeds, and age at the time of radiographic evaluation had a significant effect on progeny hip joint conformation in all breeds except the CSP. For the ES, PWD, and BMD, the youngest dogs (≤ 23 months old at the time of evaluation) had significantly higher progeny hip conformation scores than did dogs in the other 2 age categories (Table 1).

The percentage of dysplastic progeny varied considerably over time for each breed (**Table 2**), ranging from 33.8 (1979) to 8.9% (1993) for the ES, 28.6 (1984) to 7.2% (1992) for the PWD, 20.9 (1982) to 6.6% (1990) for the CSP, and 36.7 (1980) to 10.5% (1992) for the BMD. For all 4 breeds, percentages of phenotypically normal and dysplastic progeny varied significantly across birth years.

Six thousand two hundred three mid-parent offspring pairs were analyzed (ES, 1,091; PWD, 1,101; CSP, 1,070; BMD, 2,941). Mean direct heritabilities, estimated by use of midparent offspring analyses, were

Table 1—Number of progeny for which hip conformation scores were obtained and mean progeny hip score for 4 breeds of dogs, grouped on the basis of age and sex

		Mean progeny hip score (No. with score)				
Breed	No. with score	≤ 23 mo	24–35 mo	≥ 36 mo	Female	Male
English Setter	3,876	3.73 (74)	2.68 (2,779)	2.90 (1,023)	2.74 (2,234)	2.77 (1,642)
Portuguese Water Dog	1,337	3.51 (73)	2.51 (1,129)	2.75 (135)	2.50 (805)	2.71 (532)
Chinese Shar-pei	3,360	2.76 (505)	2.62 (2,283)	2.77 (572)	2.69 (2,072)	2.64 (1,288)
Bernese Mountain Dog	4,151	3.35 (161)	2.79 (3,497)	3.14 (493)	2.87 (2,571)	2.83 (1,580)

Table 2—Percentage of dysplastic progeny as a function of year of birth for 4 breeds of dogs

Year of birth	English Setter	Portuguese Water Dog	Chinese Shar-pei	Bernese Mountain Dog
1972	7/34 (20.6)	—	—	—
1973	13/41 (31.7)	—	—	—
1974	11/48 (22.9)	—	—	—
1975	12/61 (19.7)	—	—	12/39 (30.8)
1976	13/48 (27.1)	—	—	15/65 (23.1)
1977	14/61 (23.0)	—	—	20/65 (30.8)
1978	9/65 (13.8)	—	—	24/80 (30.0)
1979	24/71 (33.8)	—	—	22/62 (35.5)
1980	29/99 (29.3)	—	12/73 (16.4)	36/98 (36.7)
1981	26/163 (16.0)	—	13/93 (14.0)	36/128 (28.1)
1982	42/254 (16.5)	—	37/177 (20.9)	35/138 (25.4)
1983	38/193 (19.7)	12/52 (23.1)	52/286 (18.2)	42/156 (26.9)
1984	51/275 (18.5)	18/63 (28.6)	80/424 (18.9)	46/166 (27.7)
1985	47/245 (19.2)	26/108 (24.1)	108/632 (17.1)	58/245 (23.7)
1986	53/286 (18.5)	23/118 (19.5)	82/608 (13.5)	63/267 (23.6)
1987	39/265 (14.7)	31/146 (21.2)	52/384 (13.5)	80/319 (25.1)
1988	32/261 (12.3)	32/146 (21.9)	33/301 (11.0)	64/328 (19.5)
1989	57/312 (18.3)	22/164 (13.4)	20/187 (10.7)	67/369 (18.2)
1990	54/285 (18.9)	52/259 (20.1)	8/121 (6.6)	48/326 (14.7)
1991	47/276 (17.0)	25/227 (11.0)	—	64/441 (14.5)
1992	34/307 (11.1)	18/249 (7.2)	—	45/429 (10.5)
1993	20/225 (8.9)	32/160 (20.0)	—	48/372 (12.9)

Data represent No. of dysplastic dogs/No. of dogs for which hip conformation scores were obtained (%). Dogs with hip conformation scores of 5, 6, or 7 assigned by the Orthopedic Foundation for Animals were considered dysplastic; dogs with scores of 4 (borderline) were excluded from the analyses.
— = Data not available.

Table 3—Mean hip conformation score of the progeny and number of dysplastic progeny produced as a result of mating dogs with various hip conformation scores

Hip conformation score of the sire	Hip conformation score of the dam					
	1 (excellent)	2 (good)	3 (fair)	5 (mildly dysplastic)	6 (moderately dysplastic)	7 (severely dysplastic)
1 (excellent)						
Mean score	2.00	2.28	2.45	2.55	2.50	2.00
No. dysplastic/No. tested (%)	1/43 (2.3)	33/348 (9.5)	17/160 (10.6)	3/22 (13.6)	4/30 (13.3)	0/2 (0)
2 (good)						
Mean score	2.49	2.54	2.64	2.89	2.99	2.40
No. dysplastic/No. tested (%)	51/413 (12.3)	333/2,554 (13.0)	110/731 (15)	40/197 (20.3)	35/153 (22.9)	1/5 (20)
3 (fair)						
Mean score	2.45	2.72	2.84	3.14	3.35	4.00
No. dysplastic/No. tested (%)	12/94 (12.8)	120/741 (16.2)	55/286 (19.2)	20/83 (24.1)	12/43 (27.9)	1/2 (50)
5 (mildly dysplastic)						
Mean score	3.33	2.92	3.79	3.00	3.33	5.50
No. dysplastic/No. tested (%)	2/6 (33.3)	17/80 (21.2)	7/14 (50)	1/4 (25)	3/9 (33.3)	2/2 (100)
6 (moderately dysplastic)						
Mean score	3.27	3.04	3.72	2.50	2.78	NA
No. dysplastic/No. tested (%)	5/15 (33.3)	23/98 (23.5)	13/32 (40.6)	1/10 (10)	1/9 (11.1)	0/0
7 (severely dysplastic)						
Mean score	NA	2.75	3.00	NA	3.00	NA
No. dysplastic/No. tested (%)	0/0	2/8 (25)	1/6 (16.7)	0/0	0/3 (0)	0/0

NA = Not applicable.
See Table 2 for key.

(mean ± SE) 0.17 ± 0.05, 0.30 ± 0.06, 0.31 ± 0.05, and 0.30 ± 0.04 for the ES, PWD, CSP, and BMD, respectively, with a pooled value of 0.26 ± 0.03. Dam and sire hip conformation scores had a significant effect on progeny hip conformation scores (**Table 3**); however, the sire × dam interaction did not have a significant effect, suggesting that gene contributions by the sire and dam were equal, and little or no nonadditive gene action was involved with development of HD. Percentage of dysplastic progeny significantly increased as progeny of sires and dams with low hip conformation scores were compared with progeny of sires and dams with higher scores (ie, poorer hip joint conformation). Percentage of dysplastic progeny for sires with a hip conformation score of 1 (excellent) mated to dams with a hip conformation score of 1 was significantly less than percentage when sires with a score of 2 (good) were mated with dams with a score of 2 and when sires with score of 3 (fair) were mated with dams with a score of 3. In addition, percentage of dysplastic progeny when sires with a hip conformation score of 2 were mated with dams with a score of 2 was significantly less than percentage when sires with a score of 3 were mated with dams with a score of 3.

Regression analyses indicated that the percentage of dysplastic progeny decreased a mean of 0.64%/y in the ES, 1.12%/y in the BMD, and 1%/y in the CSP and PWD. For the 2 sexes combined, the percentage of breeding animals for which hip conformation scores were obtained increased 3.26%/y in the ES, 5.43%/y in

Table 4—Percentages of breeding dogs of 4 breeds for which hip conformation scores were obtained and percentages of dogs for which scores were obtained with phenotypically normal or dysplastic hip joints as a function of year of birth

	English Setter			Portuguese Water Dog			Chinese Shar-pei			Bernese Mountain Dog		
Year of birth	No with score/ No. of dogs (%)	No. normal (%)*	No. dysplastic (%)†	No. with score/ No. of dogs (%)	No. normal (%)*	No. dysplastic (%)†	No. with score/ No. of dogs (%)	No. normal (%)*	No. dysplastic (%)†	No. with score/ No. of dogs (%)	No. normal (%)*	No. dysplastic (%)†
1972	5/39 (12.8)	4 (80.0)	1 (20.0)	—	—	—	—	—	—	—	—	—
1973	3/38 (7.9)	2 (66.7)	1 (33.3)	—	—	—	—	—	—	—	—	—
1974	9/61 (14.8)	6 (66.7)	3 (33.3)	—	—	—	—	—	—	—	—	—
1975	14/57 (24.6)	10 (71.4)	4 (28.6)	—	—	—	—	—	—	19/75 (25.3)	13 (68.4)	6 (31.6)
1976	11/57 (19.3)	9 (81.8)	2 (18.2)	—	—	—	—	—	—	32/104 (30.8)	28 (87.5)	4 (12.5)
1977	22/62 (35.5)	16 (72.7)	6 (27.3)	—	—	—	—	—	—	46/100 (46.0)	35 (76.1)	11 (23.9)
1978	17/60 (28.3)	15 (88.2)	2 (11.8)	—	—	—	—	—	—	51/104 (49.0)	44 (86.3)	7 (13.7)
1979	29/68 (42.6)	24 (82.8)	5 (17.2)	—	—	—	—	—	—	59/101 (58.4)	51 (86.4)	8 (13.6)
1980	37/86 (43.0)	30 (81.1)	7 (18.9)	—	—	—	23/105 (21.9)	18 (78.3)	5 (21.8)	87/132 (65.9)	67 (77.0)	20 (23.0)
1981	50/112 (44.6)	40 (80.0)	10 (20.0)	—	—	—	36/145 (24.8)	28 (77.8)	8 (22.2)	108/162 (66.7)	88 (81.5)	20 (18.5)
1982	78/150 (52.0)	69 (88.5)	9 (11.5)	—	—	—	64/221 (29.0)	51 (79.7)	13 (20.3)	114/160 (71.2)	90 (78.9)	24 (21.1)
1983	62/106 (58.5)	52 (83.9)	10 (16.1)	5/19 (26.3)	3 (60.0)	2 (40.0)	110/341 (32.3)	91 (82.7)	19 (17.3)	141/201 (70.1)	119 (84.4)	22 (15.6)
1984	96/156 (61.5)	89 (91.7)	8 (8.3)	14/31 (45.2)	13 (92.9)	1 (7.1)	202/518 (39.0)	176 (87.1)	26 (12.9)	154/205 (75.1)	131 (85.1)	23 (14.9)
1985	95/132 (72.0)	90 (94.7)	5 (5.3)	36/54 (66.7)	29 (80.6)	7 (19.4)	322/787 (40.9)	278 (86.3)	44 (13.7)	182/250 (72.8)	162 (89.0)	20 (11.0)
1986	114/170 (67.1)	103 (90.4)	11 (9.6)	56/67 (83.6)	49 (87.5)	7 (12.5)	343/800 (42.9)	297 (86.6)	46 (13.4)	194/254 (76.4)	165 (85.1)	29 (14.9)
1987	117/163 (71.8)	108 (92.3)	9 (7.7)	85/100 (85.0)	71 (83.5)	14 (16.5)	270/560 (48.2)	239 (88.5)	31 (11.5)	246/308 (79.9)	217 (88.2)	29 (11.8)
1988	97/149 (65.1)	85 (87.6)	12 (12.4)	73/84 (86.9)	71 (97.3)	2 (2.7)	222/460 (48.3)	202 (91.0)	20 (9.0)	275/350 (78.6)	247 (89.8)	28 (10.2)
1989	112/179 (62.6)	106 (94.6)	6 (5.4)	90/98 (91.8)	84 (93.3)	6 (6.7)	154/310 (49.7)	141 (91.6)	13 (8.4)	332/418 (79.4)	295 (88.9)	37 (11.1)
1990	102/143 (71.3)	94 (92.2)	8 (7.8)	114/120 (95.0)	106 (93.0)	8 (7.0)	130/216 (60.2)	123 (94.6)	7 (5.4)	317/395 (80.3)	296 (93.4)	21 (6.6)
1991	90/122 (73.8)	86 (95.6)	4 (4.4)	129/138 (93.5)	126 (97.7)	3 (2.3)	—	—	—	370/463 (79.9)	343 (92.7)	27 (7.3)
1992	108/156 (69.2)	101 (93.5)	7 (6.5)	127/141 (90.1)	121 (95.3)	6 (4.7)	—	—	—	339/438 (77.4)	315 (92.9)	24 (7.1)
1993	84/116 (72.4)	81 (96.4)	3 (3.6)	79/90 (87.8)	78 (98.7)	1 (1.3)	—	—	—	388/456 (85.1)	369 (95.1)	19 (4.9)
Total	**1,352/2,381 (56.8)**	**1,219 (90.2)**	**133 (9.8)**	**808/942 (85.8)**	**751 (92.9)**	**57 (7.1)**	**1,876/4,463 (42.0)**	**1,644 (87.6)**	**232 (12.4)**	**3,454/4,676 (73.9)**	**3075 (89.0)**	**379 (11.0)**

*Percentage of dogs for which hip conformation scores were obtained that had scores of 1, 2, or 3. †Percentage of dogs for which hip conformation scores were obtained that had scores of 5, 6, or 7.

the PWD, 3.5%/y in the CSP, and 2.71%/y in the BMD (**Table 4**). Concurrently, among dogs for which hip scores were obtained, the percentage of breeding dogs that were phenotypically normal increased a mean of 1.21, 2.50, 1.65, and 0.95%/y in the ES, PWD, CSP, and BMD, respectively. The percentage of progeny that were phenotypically normal increased 0.64, 1.12, 1, and 1.12%/y in the ES, PWD, CSP, and BMD, respectively. Among progeny with phenotypically normal hip joint conformation, the percentage with excellent conformation (ie, hip conformation score of 1 vs a score of 2 or 3) increased 0.06, 0.69, 0.51, and 0.46% annually in the ES, PWD, CSP, and BMD, respectively.

Discussion

In the United States, it is impossible to determine changes in prevalence of HD in particular breeds of dogs, because a large percentage of dogs are sold as pets. Most of these pets are not bred, and hip joint conformation is typically not evaluated unless the dog develops a problem that leads to an examination by a veterinarian. The OFA database consists of radiographs submitted voluntarily by owners and breeders who want their dogs evaluated. Most radiographs that are submitted represent dogs of 1 of 4 breeds: German Shepherd Dog, Rottweiler, Labrador Retriever, and Golden Retriever.[7] On the basis of the number of dogs of these 4 breeds registered with the American Kennel Club, the OFA estimates that radiographs of only 5% of dogs of these breeds used for breeding are submitted to the OFA for evaluation. This low percentage offers some insight into problems involved with reducing the incidence of HD.[7]

Conformation of the hip joints on the standard ventrodorsal radiographic view of the pelvis is commonly used to determine which dogs in a breeding program will be bred, and previous studies[4,8,11-13] have shown that selection of breeding animals on the basis of hip conformation scores obtained by examination of this radiographic view will result in a decrease in the incidence of HD in dogs. Hip joint laxity has been recognized as a constant feature of HD in dogs.[3] For this reason, various stress radiographic techniques that laterally displace the femoral heads from the acetabulums have been developed to assess passive hip joint laxity.[14,15] Recent reports have described modified stress radiographic techniques that have been developed in an attempt to estimate amount of functional hip joint laxity by applying stress in a cranial, dorsal, and lateral direction (ie, a direction similar to the stress applied when a dog is in motion)[6] and by placing dogs in a neutral, weight-bearing position and measuring amount of femoral head subluxation.[16] To the authors' knowledge, what effect using hip conformation measurements based on results of stress radiography in dogs as the sole criterion for selecting breeding stock has on hip joint conformation of the progeny has not been published.

The 4 breeds used in the present study were chosen because of the high percentage of breeding animals for which hip conformation scores were available (during the study years, hip conformation scores were available for between 42 and 85% of breeding animals), the differences in breed conformation, and the availability of pedigree information. Because information was submitted voluntarily, caution should be used when interpreting results of the present study. In addition, because submission of radiographs for evaluation by the OFA is voluntary, we did not have hip conformation scores for every dog from every litter of parents included in this study. Common reasons why radiographs of individual dogs are not submitted for evaluation include sale of the dog as a pet, economic considerations, and death of the dog; it is also possible that the dog did not develop as expected by the breeder and, therefore, was not considered suitable as a breeding animal. There also may be various degrees of prescreening of radiographs prior to submission by veterinarians and through preliminary examinations (ie, examination of dogs ≤ 23 months old).[17] The OFA believes that any bias attributable to prescreening has remained constant over time because in a previous retrospective study[7] using the OFA database, the percentage of dogs with excellent hip joint phenotype was substantially greater than the decrease in percentage of dogs classified as having HD. This suggests that there has been an overall improvement in hip joint conformation as a result of selective breeding, rather than more stringent prescreening by referring veterinarians and owners over time prior to submission to the OFA. In addition, the percentage of dogs with normal hip joint conformation scores of 1 (vs a score of 2 or 3) should not be as influenced by prescreening, because it is more difficult to differentiate excellent hips from good hips than it is to differentiate normal hips from dysplastic hips.[7]

Sex did not have a significant effect on progeny hip conformation scores for any of the 4 breeds in the present study and accounted for only 0.1 to 0.2% of the variation in progeny hip conformation scores. Therefore, sex was ignored in subsequent calculations to determine the heritability of hip conformation scores.

The significant effect of age at the time of radiographic evaluation in all breeds except the CSP could be attributable to a combination of factors. Hip conformation scores assigned to dogs ≤ 23 months old represented the opinion of 1 radiologist, whereas scores assigned to older dogs represented the consensus of 3 radiologists. It is possible that hip conformation scores may be biased because of differences of opinion among the 3 radiologists who evaluated radiographs of dogs ≥ 24 months old. However, when results of 1.5 million radiographic evaluations by 35 radiologists were analyzed, it was found that all 3 radiologists agreed 94.9% of the time as to whether the dog should be classified as having radiographically normal phenotype, borderline phenotype, or HD. In addition, 73.5% of the time all 3 radiologists agreed on the same hip conformation score.[16] The effect of age at the time of radiographic evaluation may also be attributable to greater prescreening of radiographs of older dogs by veterinarians, because signs of secondary degenerative joint disease may be more obvious in older dogs, and radiographs of these dogs may not be submitted. There was also a large difference in the numbers of radiographs submitted for evaluation among age categories. Radiographs of dogs ≤ 23 months old made up only 1.9, 5.5, 15, and 3.9% of the total number of radiographs submitted for the ES, PWD, CSP, and BMD, respectively, and dogs between 24 and 35 months old represented the highest percentage of radiographs submitted. Because of the low number of radiographs of younger dogs that were submitted for evaluation, the significance of this fixed effect on variation in prevalence of HD was ignored in subsequent calculations of heritability.

For all 4 breeds in the present study, year of birth had a significant effect on progeny hip conformation scores. This was expected, given the annual increase in percentage of progeny with phenotypically normal hip joints and the concurrent annual decrease in percentage of progeny with dysplastic joints.

To minimize year effects on estimates of heritability, midparent offspring hip conformation scores within years were analyzed, and results were then pooled over years. Given that hip conformation scores were not available for all offspring in every litter, within-year midparent offspring regression analyses also provided a more accurate estimate from the available data. This data limitation prevented the use of other statistical tests such as use of paternal half-sib families to estimate heritability.

Estimates of heritability of HD for the 4 breeds included in the present study were comparable to previous estimates,[4,5,8,11-13] and were in the range of moderate heritability. The pooled heritability estimate of 0.26 ± 0.03 suggests that 26% of the variation in hip conformation scores was attributable to genetic differences among the animals used in the study. It is possible that years of selection against HD caused a reduction in the variation of radiographic hip joint phenotype, thereby causing a bias in estimates of heritability within a breeding population. This was avoided in the present study by estimating heritability through use of the midparent offspring regression analysis.

In the present study, dam and sire hip conformation scores had a significant effect on progeny hip conformation scores, but the sire × dam interaction did not. This implies that gene contributions from the sire and dam were equal. This is important, because breeders are often tempted to place blame on only 1 parent when litters with a high percentage of dysplastic progeny are produced. This also suggests that genes have an additive effect in inheritance of HD. Traits for which genes have an additive effect are more evident according to the number of genes present.[1] Nonadditive hereditary effects are a function of the combination of genes at various loci that influence the particular trait of interest and do not depend so much on the number of genes.[1] With traits for which genes have an additive effect like HD, breeders can use phenotype to selectively breed against HD and, in turn, lower the prevalence of the disease.[1]

The significant differences in percentages of dysplastic progeny among parents with excellent, good, and fair hip joint conformation supports the OFA recommendations that only dogs with excellent or good hip joint conformation be used in a breeding program, and use of dogs with fair conformation is questionable. In the present study, the numbers of dysplastic breeding pairs were too low to compare percentages of dysplastic offspring born to dysplastic parents with percentages of dysplastic offspring born to parents with phenotypically normal hip joints. This was expected, because most breeders selectively choose not to breed dogs with radiographic evidence of HD. If a dog with fair hip joint conformation has other highly desirable traits, compared with other members of the breed, the percentage of offspring with phenotypically normal hip joint conformation can be increased by breeding to dogs with excellent or good hip joint conformation. However, it is important to incorporate information on hip joint conformation of relatives when making breeding decisions, regardless of the hip joint conformation of the individual dog.

During the study period, 6,203 progeny for which hip conformation score was known were produced by parents for which hip conformation score was known. The annual decrease in percentage of dysplastic progeny and increase in percentage of progeny with phenotypically normal hip joint conformation (especially progeny with excellent hip joint conformation) across birth years corresponded well with the increase in percentage of breeding dogs with phenotypically normal hip joint conformation. Because these data were analyzed within birth years, rather than generations, results will not indicate as dramatic a change in progeny hip conformation scores. Changes in hip conformation scores would be of greater magnitude if changes during periods of 4 years or more, rather than every year, were analyzed. Differences in the percentages of dysplastic progeny among breeds reflect different degrees of selection pressure applied by breeders and, perhaps, differences in the heritability of HD.

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