Effectiveness of PennHIP and Orthopedic Foundation for Animals measurements of hip joint quality for breeding selection to reduce hip dysplasia in a population of purpose-bred detection dogs

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OBJECTIVE
To examine the effectiveness of applying selective pressure to improve hip joint quality in purpose-bred detection dogs by use of PennHIP distraction index (DI) values along with Orthopedic Foundation for Animals (OFA) hip joint scores and to determine whether age, sex, coat color, breed, and body weight were associated with hip joint quality.

ANIMALS
615 purpose-bred detection dogs assessed for hip joint quality.

PROCEDURES
Orthopedic records of 615 purpose-bred detection dogs (569 Labrador Retrievers and 46 Labrador Retriever–German Wirehaired Pointer crossbred dogs) from 2000 through 2017 were analyzed. From 2000 to 2014, hip joint quality scores were determined by OFA evaluation only (429 dogs). Beginning in 2015, both PennHIP and OFA evaluations were used to select male and female breeding stock (179 dogs; 7 dogs were removed from analysis because they did not undergo both evaluations). Selection threshold DI value for sires and dams was ≤ 0.30; all had hip joint scores of excellent or good by OFA standards. Standard ventrodorsal hip joint–extended and stress (compression and distraction) pelvic radiographs were submitted for OFA and PennHIP evaluations.

RESULTS
Hip joint quality scores were unchanged by use of OFA measurements only. When both PennHIP and OFA measurements were used for the selection of breeding stock, hip joint quality scores improved significantly. Sex and age were significant predictors of DI values.

CONCLUSIONS AND CLINICAL RELEVANCE
PennHIP DI values were an effective measurement of hip joint quality for selecting breeding stock, and the addition of DI values to OFA measurements significantly improved hip joint quality in a population of purpose-bred dogs.
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Canine hip dysplasia is the most commonly inherited orthopedic disease in dogs. Described by Schnelle in 1935[1] as a malformation of the hip joint, it has since been recognized as the primary orthopedic disease affecting medium- to large-breed dogs.[2–4] Canine hip dysplasia is expressed by a shallow acetabulum, subluxation of the femoral head, changes in the shape of the femoral head or neck, or periarticular osteophytes[5] and can be influenced by environmental factors.[6,7] Canine hip dysplasia is a polygenic and multifactorial disease that is highly heritable.[4,8–10] Studies[5,9–14] have shown, in various populations and breeds, that CHD heritability estimates range from 0.10 to 0.60.

ABBREVIATIONS

CHD	Canine hip dysplasia
DI	Distraction index
DJD	Degenerative joint disease
OFA	Orthopedic Foundation for Animals

Riser[15] stated that maintaining stability and congruency in the hip joint could prevent CHD in young dogs. Hip joint laxity is an early sign of CHD,[16] and primary joint laxity causes the changes in the acetabulum.[11] Degenerative joint disease occurs when the femoral acetabulum contact is altered, resulting in an abnormal position of the femoral head and acetabulum and causing instability.[15] Environmental factors, age, breed, body weight, frame size, strenuous activity, or poor muscle mass influence hip joint laxity.[5–7,11,17,18] Degenerative joint disease occurs when passive hip joint laxity converts to weight-bearing laxity.[7]

The OFA provides a subjective hip joint quality scoring method that has been used as a diagnostic tool since 1966[3] and is the most prevalent hip joint measurement tool used in the world.[16,19] A 7-point grading scale is used to describe hip quality from ventrodorsal hip joint–extended pelvic radiographs. On radiographic evaluation, nondysplastic hip joints are classified as excellent, good, or fair, and dysplastic hip joints are classified as mild, moderate, or severe. Hip joints are classified as borderline if no arthritic changes are present but they have more incongruity than in hip joints classified as fair. Subjective measures are best used in dogs ≥ 24 months of age. The false-negative rate of evaluation is much higher in dogs < 24 months of age.[20] In the last 4 decades, Labrador Retriever OFA hip joint scores have shown variable improvements in hip joint quality, but the overall proportion of hip joints classified as excellent has increased by 24%. The overall proportion of hip joints classified as excellent increased in 2000 to 2007 from 22% to 27%.[13]

The PennHIP evaluation measures passive hip joint laxity from radiographic views of the pelvis under stress (ie, compression and distraction views).[7] When a distraction force is applied to the pelvis, the femoral head displaces from the center of the acetabulum by a measurable distance that is divided by the radius of the femoral head, which yields a unitless measure of joint laxity.[7] Scores range from 0 to 1 (or more), with 0 considered as having no laxity and 1 considered as severe laxity. Distraction index values have been shown to be more accurately predictive of the risk of developing DJD than subjective hip joint scoring methods for dogs < 24 months of age.[7,18]

Working dogs in canine detection programs protect against current and emerging threats, and the demand for specialized detection dogs has increased.[21,22] Otherwise successful detection dogs are rejected from service because of poor hip joint quality ratings. Evans et al[23] found DJD to be one of the primary reasons for discharge of Department of Defense military working dogs ≥ 5 years of age. Reducing and eliminating CHD through selective breeding are imperative for improving the functionality and working longevity of detection dogs. To reduce CHD in a population, pedigree depth should be established and only dogs with nondysplastic hip joints should be mated.[8] Breeding programs should examine phenotypic expressions of CHD across several generations when making sire and dam selections.[4,16] The purpose of the study reported here was to examine the effectiveness of applying selective pressure to improve hip joint quality in a purpose-bred detection dog population by use of the PennHIP DI value along with the OFA hip joint quality rating system and to determine whether age, sex, coat color, breed, and body weight were associated with hip joint quality.

Materials and Methods

Animals

Orthopedic records of 615 dogs (315 males, 300 females) from the Auburn University College of Veterinary Medicine-Canine Performance Sciences breeding program between 2000 and 2017 were analyzed. The population consisted of Labrador Retrievers (n = 569) from 102 litters from 43 dams and 47 sires, and Labrador Retriever–German Wirehaired Pointer crossbred dogs (46) from 8 litters of F1, F2, and F3 generations from 6 dams and 6 sires. Seven dogs were removed from the 2015 to 2017 analysis because they had undergone only 1, not both OFA and PennHIP evaluations.

Dogs were presented to the Bailey Small Animal Teaching Hospital at the Auburn University College of Veterinary Medicine for routine hip joint radiographic evaluation. Radiography was not conducted if females were in estrus. Dogs were sedated, and standard ventrodorsal hip joint–extended and stress (ie, compression and distraction) radiographic views of the pelvis were obtained and submitted for OFA and PennHIP evaluations, accordingly. PennHIP-certified veterinarians (JH and RL) participated in obtaining the radiographic views. The worst-rated hip joint without regard to hip joint of origin (ie, left or right) as indicated by OFA hip joint score or DI value was selected for use in statistical analysis. For the purpose of statistical analysis, dogs were grouped into fiscal year contemporary groups on the basis of their birth date. The fiscal year spanned from October 1 to September 30 (eg, a dog born in December 2000 would be in the fiscal year 2001 group).

Prior to 2015, the only hip joint requirements for breeding stock were to have excellent or good OFA hip joint scores. Since 2015, hip joint requirements for matriculation as breeding stock were a DI value of ≤ 0.30 and an OFA hip joint score of excellent or good. Dogs with excellent or good OFA hip joint scores and DI slightly > 0.30 were infrequently permitted as breeding stock because of their other outstanding behavioral phenotypes. Successful detection dogs must possess certain behavioral characteristics, such as the ability to hunt, focus, and work independently.[24] After all breeding stock medical requirements were satisfied (eg, free of CHD), mating selections were based on inbreeding coefficients, management of other genetic traits (eg, exercise-induced collapse), and behavioral characteristics.

Dog care and use activities were approved and monitored by the Auburn University Institutional Animal Care and Use Committee.

Statistical analysis

Commercially available software[a] was used for data analysis. To assess whether hip joint quality scores improved over time, the Kendall rank (τ) and Spearman rank-order (r) correlations were run to determine relationships between OFA hip joint score and fiscal year (before and after implementing PennHIP evaluation as a selective breeding technique) and DI value and fiscal year, respectively. A Pearson χ^2 test of homogeneity was used to analyze the effectiveness of the use of DI values in improving OFA hip joint scores. Dogs missing either measurement (ie, DI value or OFA hip joint score) were removed from the analysis. A Spearman rank-order correlation was determined to assess the relationship between OFA and DI screening methods for detecting evidence of CHD. Multiple regression analysis was used to evaluate age, sex, coat color, breed, and body weight as predictors of DI value. A Pearson χ^2 test was performed to evaluate the association of sex with OFA hip joint score. For all tests, values of $P \leq 0.05$ were considered significant.

Genetic software[b] was used for heritability analysis. Four measures of hip joint scores based on the DI values were used for this analysis as follows: right hip joint score, left hip joint score, mean hip joint score (average value of right and left hip joint scores), and final hip joint score (maximum value of the right and the left hip joint scores). A quantitative trait maximum likelihood model with sex as a covariate was used. Values of $P < 0.05$ were considered significant.

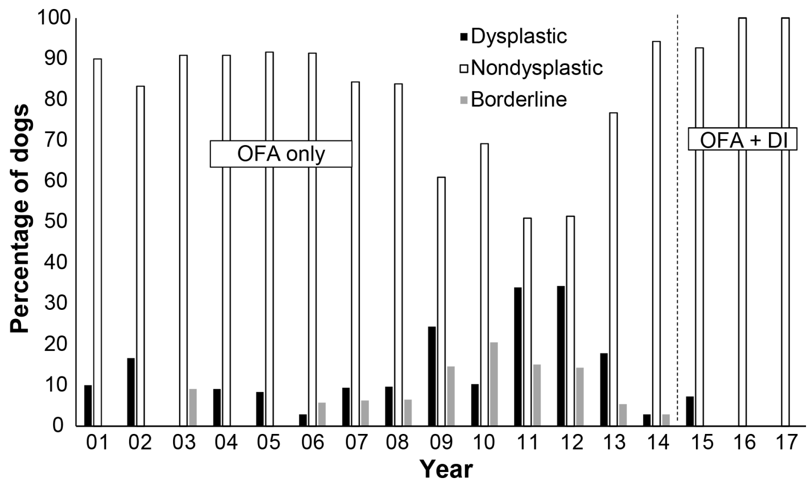

Figure 1—Percentage of 608 purpose-bred detection dogs with hip joints that were considered nondysplastic, dysplastic, or borderline on the basis of OFA evaluation from 2001 through 2017. The vertical dashed line indicates the introduction of PennHIP evaluation along with OFA evaluation as a breeding selection tool in 2015.

Results

From 2001 through 2014, 429 dogs were assessed by OFA evaluation only. From 2015 through 2017, 179 dogs were assessed by both OFA and DI screening methods for detecting evidence of CHD. Seven dogs were removed from the 2015 through 2017 analysis because they had undergone only 1 but not both OFA and PennHIP evaluations.

The mean ± SD age of dogs that were evaluated was 10.85 ± 1.27 months. The mean ± SD body weight of evaluated dogs was 27.35 ± 3.62 kg (60.17 ± 7.96 lb). Since 2015, Labrador Retriever sires and dams (n = 16) had a mean ± SD DI value of 0.37 ± 0.10 and Labrador Retriever–German Wirehaired Pointer crossbred sires and dams (3) had a mean ± SD DI value of 0.38 ± 0.08.

From 2001 through 2014, the correlation between OFA hip joint scores and year (ie, before the implementation of PennHIP evaluation) was not significant ($\tau = -0.044$; $P = 0.242$). From 2015 through 2017, the correlation between OFA hip joint scores of dogs and year (ie, during which time the PennHIP evaluation was used in combination with OFA evaluation) was significant (positive correlation, $\tau = 0.249$; $P < 0.001$). The decrease in DI values across years was not significant ($r = -1.06$; $P = 0.156$).

Of dogs assessed by only OFA evaluation from 2001 through 2014, 75% (323/429) had nondysplastic hip joints (ie, OFA hip joint scores of excellent, good, or fair) and 16% (68/429) had dysplastic hip joints (ie, OFA hip joint scores of mild, moderate, or severe). Nine percent (38/429) of dogs had borderline hip joints on the basis of OFA evaluation. After implementing selective breeding with the incorporation of PennHIP evaluation, the percentage of dogs with nondysplastic hip joints increased by 22 percentage points to 97% (181/186), whereas 3% (5/186) of dogs had dysplastic hip joints and none had borderline hip joints (**Figure 1**). The decrease in the percentage of dogs with dysplastic hip joints after the introduction of DI values was significant ($P < 0.001$). The mean DI value for the entire population was 0.38 ± 0.10. A significant ($r = -0.279$; $P < 0.001$) negative correlation was found between DI and OFA screening methods for detecting evidence of CHD; as OFA scores improved, DI values decreased.

Results of multiple regression analysis that included age, sex (male vs female), coat color (black, yellow, or chocolate), breed (Labrador Retriever vs Labrador Retriever–German Wirehaired Pointer crossbred dogs), and body weight as predictors of DI values indicated that only sex and age were significant ($P < 0.001$) predictors of the DI value. An increase in age was associated with a decrease in the DI value, and dogs closer to 11 months of age had less hip joint laxity than younger dogs. Sex was a significant predictor of DI values, and female was associated with an increase in DI values. Hip joint scores obtained by OFA standards did not, however, differ ($P = 0.614$) by sex.

Heritability analysis of OFA hip joint scores for 189 dogs revealed that the total additive genetic heritability score was 0.18 to 0.26 for all 4 hip joint score phenotypes, and all heritability scores were significantly (ie, $P < 0.05$) > 0. In all models fitted for the 4 CHD heritability scores, the effect of sex was not significant.

Discussion

The demand of specialized dogs for the detection of hazardous materials and emerging threats has steadily increased during the last several years.[21,22] Degenerative joint disease, the phenotypic expression of CHD, is one of the primary reasons for release of military working dogs ≥ 5 years of age.[23] In 2007, Evans et al[23] found that 42 of 160 military working dogs were discharged from service because of DJD alone or DJD in conjunction with spinal cord disease. Reducing and eliminating CHD through selective breeding could improve the functionality and working longevity of detection dogs. In the study reported here, we examined the effectiveness of applying selective pressure with PennHIP DI values along with hip joint scores obtained by OFA standards to reduce the prevalence of CHD in a population of purpose-bred detection dogs.

In the present study, the addition of DI values as a selection tool for breeding animals significantly improved the OFA hip joint scores of the population from 2015 through 2017. Dogs deemed to have tight (nonlax) hip joints when screened by use of objective measures (ie, DI value < 30) have minimal risk of developing CHD.[7,18] In contrast, following the subjective OFA guidelines by only breeding dogs with hip joint confirmation classified as excellent or good, no significant progress had been made in our population during the course of 13 years. Historically, subjective scoring methods, such as OFA evaluation, have produced measurable effects on breeding populations.[13] However, researchers have recently found that excess joint laxity, as seen by radiographic views included in PennHIP evaluation, was not always apparent on the standard hip joint–extended pelvic radiographs used by subjective scoring methods, allowing dogs with greater hip laxity to be inaccurately judged as having good-quality hip joints.[7,25] Dogs with even good subjective hip joint quality scores may produce affected offspring.[5,25]

The addition of DI values to hip joint scores obtained by OFA standards created a stronger individual phenotype grade for hip joints. Use of the OFA guidelines was successful in removing dogs most at risk for CHD from our population; however, the addition of DI values as a breeding selection tool substantially accelerated the progress. The use of DI values significantly improved our population's OFA hip joint scores by 22 percentage points during a 3-year period, which supports the findings from the 1977 study of Leighton,[16] who found a significant decrease in CHD in a population of Labrador Retrievers and German Shepherd Dogs by using a combination of DI values and subjective radiographic scores to determine breeding stock replacements.

Studies[4,5] have reported CHD occurring more frequently in female dogs, but most studies[4,12,13,17,26–29] found no sex predilection. Sex was not a significant factor for the prevalence of CHD in our population, which agreed with the results of other studies[12,13]; however, sex and age were significant predictors of DI value in our population. Female dogs in our population had significantly more laxity in their hips than male dogs, which supports the findings of Ginja et al[19] from a population of Estrela Mountain Dogs. This difference could be attributed to the hormonal difference in males and females. One study[30] found puppies that ingested increased amounts of immunoactive relaxin, estrogen, and estrogen precursor concentrates via their dam's milk were found to have increased hip joint laxity later in life. Dogs in our population closer to 11 months of age had less hip laxity than younger dogs; however, had the number of older dogs included increased, we may expect a parabolic function because DJD disease susceptibility increases with age.[18]

The use of selective breeding in our population of dogs resulted in an increased prevalence of hip joints classified as good by OFA standards and a decreased prevalence of hip joints classified as mild, moderate, and severe by OFA standards; these findings supported the theory that CHD is a polygenic trait.[4,8,9] Heritability of OFA hip joint score in our population ranged from 0.18 to 0.26, indicating that CHD is a mildly heritable trait. Other studies reported similar heritability of CHD ranging from 0.22 to 0.30 in various dog breeds,[12,31] whereas in a recent study,[14] the heritability analysis of CHD in Labrador Retrievers revealed a higher rate of 0.59. Variances in heritability may be caused by the various breeds studied, evaluation of hip joint phenotype, method used for heritability calculation, or sample sizes. Sex was not a significant factor for the presence of CHD in our population, which agreed with the results of other studies.[12,13]

The use of estimated breeding values has been shown to be effective in reducing CHD in populations of dogs.[16,32] Estimated breeding values calculate a dog's genetic risk for developing specific conditions by use of pedigree relationships along with heritability estimates.[16] Zhang et al[33] suggested using a joint estimated breeding value from DI values, dorsolateral subluxation measurements, Norberg angles, and hip joint–extended radiographic measures to decrease CHD in breeding populations.[33]

Organizations in the United States have developed estimated breeding value analyses for breeders to access free online, based on publicly registered OFA scores. Although databases like these may continue to help eliminate dogs most at risk for CHD from the overall population, it may not substantially reduce CHD in breeding populations in a timely manner.[13] One challenge in accessing estimated breeding values with only the use of OFA hip joint scores is that not all progeny are included. From 1970 to 2000, only dogs with hip joint scores classified as excellent, good, and fair by OFA standards were publicly reported.[13] Breeding animals examined by use of subjective scores alone may produce affected offspring.[5,25] When estimating breeding values to improve OFA hip joint scores, the population's hip joint heritability estimates must be understood,[16] and for breeders without complete pedigree evaluation or access to that level of management, the addition of PennHIP evaluation for sire and dam selection to reduce CHD is appropriate and cost-effective. To make progress in reducing CHD in a breeding population, breeders should determine their population mean DI value and select breeding stock that has a DI value that is lower than their population mean DI value. Worth et al[34] and Ginja et al[35] found that PennHIP evaluation was the best method for making greater gains over fewer generations in German Shepherd Dogs and Estrela Mountain Dogs, respectively, which supports our findings presented here.

Dogs leave our population to begin work around 12 months of age; therefore, documenting that dogs were negative for CHD at 24 months of age was not possible. Further, because of the retrospective and correlational nature of this study, we cannot conclusively claim a causal effect of DI values on OFA hip joint scores. Through selective breeding validated by OFA and PennHIP evaluations, however, our population has been free from CHD since the fiscal year of 2015.

Regardless of these limitations, our data suggested that PennHIP evaluation is effective at reducing the prevalence of CHD in a breeding population. Our findings indicated that DI values should be used when selecting breeding stock as it produces a quantifiable value and has been shown to significantly improve OFA hip joint scores in a population of purpose-bred working dogs.

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The authors declare that there were no conflicts of interest.

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Footnotes

a. SPSS, version 25.0 for Windows, SPSS Inc, Chicago, Ill.
b. SOLAR-Eclipse genetic software, University of Maryland, Catonsville, Md. Available at: solar-eclipse-genetics.org/. Accessed Feb 5, 2019.

References

1. Schnelle GB. Some new diseases in dogs. *Am Kennel Gazette* 1935;52:25–26.
2. Bouw J. Hip dysplasia and dog breeding. *Vet Q* 1982;4:173–181.
3. Corley EA. Role of The Orthopedic Foundation for Animals in the control of canine hip dysplasia. *Vet Clin North Am Small Anim Pract* 1992;22:579–593.
4. Swenson L, Audell L, Hedhammar A. Prevalence and inheritance of and selection for hip dysplasia in seven breeds of dogs in Sweden and benefit: cost analysis of a screening and control program. *J Am Vet Med Assoc* 1997;210:207–214.
5. Hedhammar A, Olsson SE, Andersson SA, et al. Canine hip dysplasia: study of heritability in 401 litters of German Shepherd dogs. *J Am Vet Med Assoc* 1979;174:1012–1016.
6. Riser WH. An analysis of the current status of hip dysplasia in the dog. *J Am Vet Med Assoc* 1964;144:709–721.
7. Lust G, Williams AJ, Burton-Wurster N, et al. Joint laxity and its association with hip dysplasia in Labrador Retrievers. *Am J Vet Res* 1993;54:1990–1999.
8. Riser WH. Canine hip dysplasia: cause and control. *J Am Vet Med Assoc* 1974;165:360–362.
9. Leighton EA, Linn JM, Willham RL, et al. A genetic study of canine hip dysplasia. *Am J Vet Res* 1977;38:241–244.
10. Henricson B, Ljunggren G, Olsson SE. Canine hip dysplasia in sweden. Incidence and genetics. *Acta Radiol Suppl* 1972;319:175–180.
11. 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.
12. Hou Y, Wang Y, Lu X, et al. Monitoring hip and elbow dysplasia achieved modest genetic improvement of 74 dog breeds over 40 years in USA. *PLoS One* 2013;8:e76390.
13. Hou Y, Wang Y, Lust G, et al. Retrospective analysis for genetic improvement of hip joints of cohort labrador retrievers in the United States: 1970–2007. *PLoS One* 2010;5:e9410.
14. Oberbauer AM, Keller GG, Famula TR. Long-term genetic selection reduced prevalence of hip and elbow dysplasia in 60 dog breeds. *PLoS One* 2017;12:e0172918.
15. Riser WH. The dog as a model for the study of hip dysplasia. Growth, form, and development of the normal and dysplastic hip joint. *Vet Pathol* 1975;12:234–334.
16. Leighton EA. Genetics of canine hip dysplasia. *J Am Vet Med Assoc* 1997;210:1474–1479.
17. Riser WH, Cohen D, Lindqvist S, et al. Influence of early rapid growth and weight gain on hip dysplasia in the German Shepherd Dog. *J Am Vet Med Assoc* 1964;145:661–668.
18. Smith GK, Mayhew PD, Kapatkin AS, et al. Evaluation of risk factors for degenerative joint disease associated with hip dysplasia in German Shepherd Dogs, Golden Retrievers, Labrador Retrievers, and Rottweilers. *J Am Vet Med Assoc* 2001;219:1719–1724.
19. Ginja MM, Silvestre AM, Ferreira AJ, et al. Passive hip laxity in Estrela Mountain Dog–distraction index, heritability and breeding values. *Acta Vet Hung* 2008;56:303–312.
20. Jessen CR, Spurrell FA. Radiographic detection of canine hip dysplasia in known age groups, in *Proceedings.* Canine Hip Dysplasia Symp Workshop 1972;93–100.
21. Hayes JE, McGreevy PD, Forbes SL, et al. Critical review of dog detection and the influences of physiology, training, and analytical methodologies. *Talanta* 2018;185:499–512.
22. Leighton EA, Hare E, Thomas S, et al. A solution for the shortage of detection dogs: a detector dog center of excellence and a cooperative breeding program. *Front Vet Sci* 2018;5:284.
23. Evans RI, Herbold JR, Bradshaw BS, et al. Causes for discharge of military working dogs from service: 268 cases (2000–2004). *J Am Vet Med Assoc* 2007;231:1215–1220.
24. Lazarowski L, Haney PS, Brock J, et al. Investigation of the behavioral characteristics of dogs purpose-bred and prepared to perform vapor wake detection of person-borne explosives. *Front Vet Sci* 2018;5:50.
25. Powers MY, Karbe GT, Gregor TP, et al. Evaluation of the relationship between Orthopedic Foundation for Animals' hip joint scores and PennHIP distraction index values in dogs. *J Am Vet Med Assoc* 2010;237:532–541.
26. Popovitch CA, Smith GK, Gregor TP, et al. Comparison of susceptibility for hip dysplasia between Rottweilers and German Shepherd Dogs. *J Am Vet Med Assoc* 1995;206:648–650.
27. Priester WA, Mulvihill JJ. Canine hip dysplasia: relative risk by sex, size, and breed, and comparative aspects. *J Am Vet Med Assoc* 1972;160:735–739.
28. Smith GK, Popovitch CA, Gregor TP, et al. Evaluation of risk factors for degenerative joint disease associated with hip dysplasia in dogs. *J Am Vet Med Assoc* 1995;206:642–647.
29. Larsen JS, Corley EA. Radiographic evaluations in a canine hip dysplasia control program. *J Am Vet Med Assoc* 1971;159:989–992.
30. Steinetz BG, Williams AJ, Lust G, et al. Transmission of relaxin and estrogens to suckling canine pups via milk and possible association with hip joint laxity. *Am J Vet Res* 2008;69:59–67.
31. Wilson BJ, Nicholas FW, James JW, et al. Heritability and phenotypic variation of canine hip dysplasia radiographic traits in a cohort of Australian German Shepherd Dogs. *PLoS One* 2012;7:e39620.

32. Soo M, Worth A. Canine hip dysplasia: phenotypic scoring and the role of estimated breeding value analysis. *N Z Vet J* 2015;63:69–78.
33. Zhang Z, Zhu L, Sandler J, et al. Estimation of heritabilities, genetic correlations, and breeding values of four traits that collectively define hip dysplasia in dogs. *Am J Vet Res* 2009;70:483–492.
34. Worth AJ, Laven RA, Erceg VH. An assessment of the agreement between the New Zealand Veterinary Association Hip Dysplasia Scoring System and the PennHIP Distraction Index in German Shepherd Dogs. *N Z Vet J* 2009;57:338–345.
35. Ginja MM, Gonzalo-Orden JM, Melo-Pinto P, et al. Early hip laxity examination in predicting moderate and severe hip dysplasia in Estrela Mountain Dog. *J Small Anim Pract* 2008;49:641–646.

From this month's *AJVR*

Pharmacokinetics of amantadine after oral administration of single and multiple doses to orange-winged Amazon parrots (*Amazona amazonica*)

Kyra J. Berg et al

OBJECTIVE
To determine the pharmacokinetics of amantadine after oral administration of single and multiple doses to orange-winged Amazon parrots (*Amazona amazonica*).

ANIMALS
12 adult orange-winged Amazon parrots (6 males and 6 females).

PROCEDURES
A single dose of amantadine was orally administered to 6 birds at 5 mg/kg (n = 2), 10 mg/kg (2), and 20 mg/kg (2) in a preliminary trial. On the basis of the results, a single dose of amantadine (10 mg/kg, PO) was administered to 6 other birds. Two months later, multiple doses of amantadine (5 mg/kg, PO, q 24 h for 7 days) were administered to 8 birds. Heart rate, respiratory rate, behavior, and urofeces were monitored. Plasma concentrations of amantadine were measured via tandem liquid chromatography–mass spectrometry. Pharmacokinetic parameter estimates were determined via noncompartmental analysis.

RESULTS
Mean ± SD maximum plasma concentration, time to maximum plasma concentration, half-life, and area under the concentration-versus-time curve from the last dose to infinity were 1,174 ± 186 ng/mL, 3.8 ± 1.8 hours, 23.2 ± 2.9 hours, and 38.6 ± 7.4 µg•h/mL, respectively, after a single dose and 1,185 ± 270 ng/mL, 3.0 ± 2.4 hours, 21.5 ± 5.3 hours, and 26.3 ± 5.7 µg•h/mL, respectively, at steady state after multiple doses. No adverse effects were observed.

CONCLUSIONS AND CLINICAL RELEVANCE
Once-daily oral administration of amantadine at 5 mg/kg to orange-winged Amazon parrots maintained plasma concentrations above those considered to be therapeutic in dogs. Further studies evaluating safety and efficacy of amantadine in orange-winged Amazon parrots are warranted. (*Am J Vet Res* 2020;81:650–654)

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