Advances in diagnosing canine hip dysplasia

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Canine hip dysplasia (CHD) was first described by Schnelle in the mid-1930s. It was termed "bilateral congenital subluxation of the coxofemoral joints" and was thought to be rare at that time. Today, however, we recognize that CHD is the most common orthopedic disease in large and giant-breed dogs. Although our understanding of CHD has evolved over the years, progress has often been a result of clinical empiricism than well-conceived scientific investigation, and CHD continues to be a source of considerable debate, controversy, and conjecture among veterinarians, dog breeders, and dog owners. The controversy notwithstanding, it is generally accepted that hip joint laxity plays an important role in CHD.

The simplest definition of hip dysplasia is a literal translation from its Latin roots: "faulty development of the hip." A more descriptive definition was introduced by Henricson et al in 1966; hip dysplasia is "a varying degree of laxity of the hip joint permitting subluxation during early life, giving rise to varying degrees of shallow acetabulum and flattening of the femoral head, [and] finally inevitably leading to osteoarthritis." Therefore, the connection between joint laxity at a young age and subsequent development of osteoarthritis in dogs with CHD was recognized early. Research at the University of Pennsylvania during the past 14 years has explored this connection in greater depth and has led to the development of a stress radiographic method for detecting susceptibility to CHD in young dogs. The purpose of this review is to provide background information on the body of research that supports this method.

Prevalence of CHD

Canine hip dysplasia can affect all breeds of dogs; however, it is most common in large and giant breeds. Prevalence varies by breed, and the Orthopedic Foundation for Animals (OFA) has estimated that for many of the popular breeds of dogs, the breed prevalence of CHD is between 10 and 48%, with Saint Bernards being the most commonly affected. It is generally recognized, however, that these percentages may be lower than the true breed prevalences, because some owners submit only those hip radiographs with the greatest likelihood of being certified as normal. In a review of records at the veterinary hospital of the University of Pennsylvania, for instance, only 56% of the clients who requested and paid for hip radiographs between 1991 and 1993 submitted them to the OFA for official interpretation. When all radiographs were assessed by a radiologist at the University of Pennsylvania, dogs with radiographs that were not submitted had a 10-fold higher prevalence of CHD than did dogs with radiographs that were submitted. Interestingly, the percentage of hip radiographs submitted to the OFA varied by breed. For example, 14 of 19 (74%) hip radiographs for Rottweilers were submitted to the OFA for analysis, but only 4 of 19 (21%) hip radiographs for Golden Retrievers were submitted, suggesting that Golden Retriever prevalence figures may have greater bias than those for Rottweilers. Therefore, a separate study was conducted to arrive at a truer estimate of CHD prevalence. A random sample of radiographs of 200 Golden Retrievers and 132 Rottweilers were obtained from the PennHIP (University of Pennsylvania Hip Improvement Program) database, and hip joint status was subjectively scored by a board-certified veterinary radiologist according to strict and lenient criteria. When strict scoring criteria were used to evaluate radiographs (ie, dogs with even the slightest abnormality were considered to have CHD), 148 of 200 (74%) Golden Retrievers and 91 of 132 (69%) Rottweilers were considered to have CHD (breed prevalences reported by the OFA for Golden Retrievers and Rottweilers were 23.5 and 23.3%, respectively). When hip radiographs were scored leniently, 106 of 200 (53%) Golden Retrievers and 54 of 132 (41%) Rottweilers were scored as having CHD. It is clear, irrespective of which figures one chooses to believe, that prevalence of CHD is extremely high.

Causes of CHD

Canine hip dysplasia is thought to have a genetic basis, and estimates of the heritability of CHD range from 0.2 to 0.6. Clearly, however, nongenetic factors also play a role in the expression of CHD. Some of the genetic and nongenetic factors that have been studied include body size, growth rate, nutrition, dietary anion gap, in utero endocrine influences, and muscle mass. Despite these factors, the precise cause of CHD remains unknown.

Diagnosis

A tentative diagnosis of CHD can be made on the basis of history, clinical signs, and results of palpation. By convention, however, a definitive diagnosis is made only if characteristic signs of CHD are evident on radiographs of the pelvis. Radiography is performed with the dog, preferably sedated, in dorsal recumbency, its legs fully extended, and its stifles internally rotated. This is the position advocated by the OFA and has been considered the standard for more than 30 years worldwide. A diagnosis of CHD is made if there is radiographic evidence of hip joint subluxation, degenerative joint disease (DJD) or both. Radiographic evi...
Methods of Assessing Susceptibility to CHD

Because CHD is such a common disease afflicting many dog breeds, various methods of characterizing radiographic changes associated with the disease have been developed. Methods that, from a clinical point of view, would be most useful are those that not only provide an assessment of severity of CHD (amount of joint laxity and severity of degenerative changes) at the time radiographs were obtained, but also provide information on the probability that a dog will develop DJD in the future or will pass on the genes for CHD to its offspring.

Hip palpation—Diagnostic methods of hip palpation, such as those of Ortolani,17 Bardens,18 and Barlow,19 have been used to provide semiquantitative information regarding joint laxity and associated CHD susceptibility. Although useful in diagnosing congenital hip dislocation in human neonates, hip palpation has not been demonstrated to have clear diagnostic or prognostic value in dogs to date.

Subjective hip score—Various schemes for scoring severity of radiographic changes associated with CHD have gained international acceptance. Although these scoring systems differ in detail, all depend on a subjective assessment of the relative degree of joint laxity (subluxation) and the severity of DJD evident on a hip-extended, ventrodorsal, radiographic projection of the pelvis. Unfortunately, use of such scoring methods is fraught with problems because of variations in interpretations among radiologists. Few scientific investigations have been performed to assess how much variation there is among radiologists in assigning hip scores or to determine the relationship between hip scores and heritability or breeding value.

The effect of diagnostic variation (error) in determining a disease phenotype is to lower the estimate of heritability of the phenotypic trait. Low heritability, in turn, equates to slow rate of genetic change derived from the application of selection pressure.

In 1 study,20 standard hip-extended ventrodorsal radiographic projections from 125 large and giant-breed dogs > 2 years old were evaluated for signs of CHD by 3 board-certified veterinary radiologists and the OFA, who assigned hip scores using the 7-point scoring scheme advocated by the OFA. The x statistic was used to measure the level of agreement in hip scores, with 0 representing no agreement and 1 representing perfect agreement. The level of agreement between each of the 3 radiologists and the OFA was poor; x values ranged from 0.04 to 0.20. Within-radiologist (each radiologist scoring the same set of hip radiographs 2 separate times) variability was slightly better; x values ranged from 0.38 to 0.45. When a 2-point scoring scheme (normal vs dysplastic) was used, x values ranged from 0.31 to 0.68, which was still considered low. Radiologists scored more hip joints as dysplastic than did the OFA by a factor of 25 to 300%; thus, the OFA was more lenient in scoring than were radiologists included in the study. The wide diagnostic variability and lenient hip scoring of the OFA serve to lower the calculated heritability of these scores, thereby slowing genetic change when subjective hip score is used as a selection criterion.

Heritability (h2) is defined as the ratio of additive genetic variation (Vg) to the overall phenotypic variation (Vp) of a given trait (h2 = Vg/Vp). Factors such as diagnostic error that increase the variance components in the denominator of this relationship have the effect of lowering the estimates of heritability. When owners select breeding stock on the basis of each individual animal's phenotype, which is the predominant mode of selection in the United States (ie, progeny testing is not widely used), the heritability of traits becomes extremely important, because for a quantitative trait (such as CHD), the rate of expected genetic change per generation is equal to the heritability times the selection pressure (how much the parents deviate from the population average for that trait). Therefore, the higher the heritability of a specific trait and the greater the selection pressure applied, the more rapid the expected genetic change per generation of breeding. Unfortunately, few studies of the heritability of subjective hip scores have been published. A thorough literature search could not find published estimates of the heritability of OFA scores. In 2 well-executed studies, heritabilities of subjective hip scores similar to those of the OFA were 0.2210 and 0.4311 for German Shepherd Dogs. For a given phenotypic trait, heritability estimates are population parameters and vary with the population studied. These estimates were calculated for particular populations of German Shepherd Dogs more than 15 years ago when, presumably, variation in disease phenotype was greater than it is today. Years of selection would have been expected to narrow the present range of hip joint phenotype, making present-day estimates of heritability even lower.30 As variation in phenotype (ie, subjective hip score) decreases with selective breeding, there may come a point at which little additional incremental selection pressure can be applied (eg, if all breeding dogs have the same score). That is, if the application of maximum selection pressure (eg, breeding excellent to excellent) still produces affected offspring, more genetic progress cannot be expected (short of incorporating breeding values in making selection decisions). Such has been the experience of The Seeing Eye Inc after 17 years of selection against CHD using a subjective scoring scheme similar to but more strict than that of the OFA (E Leighton, unpublished data, 1997).

Norberg angle method—The Norberg angle (NA) is a measure of joint laxity determined from the standard, hip-extended, ventrodorsal radiographic projection. The method has been used primarily in Europe and only sporadically in the United States, usually as an investigational, rather than a clinical, tool. Norberg angles typically range from 55° to 115°; with smaller angles indicating greater laxity. Studies have not been conducted to determine the NA associated
with normal hip joint laxity or the diagnostic use of NA. One report\(^1\) suggests a priori that an NA > 105° is normal. In the author's experience, however, many hips that appear normal radiographically have an NA < 105°, including some in performance Borzois and racing Greyhounds. It is possible, therefore, that a cutoff of 105° is too stringent. This view is corroborated by a study (GK Smith, unpublished data, 1997) relating NA to OFA score. It was found that 100 of 226 (44%) dogs judged to have normal hip joints by the OFA had an NA < 105°. The lowest NA associated with a normal OFA score was 88°. This discrepancy between subjective hip scores and NA may explain the poor acceptance of the NA method as a tool for diagnosis of CHD.

**Stress radiography and the distraction index**—A new stress-radiographic diagnostic method of assessing susceptibility to DJD has been reported.\(^3\)\(^7\) The method involves direct measurement of joint laxity and was based on the empirically accepted principle that joint laxity portended the development of DJD. The focus of the research to validate the method was the role of joint laxity in the formation of DJD.

The motivation to develop an improved diagnostic method was manifold. It was clear that prevalence of CHD was high, even in the face of concerted efforts on the part of dog breeders and veterinarians to reduce CHD incidence by selective breeding using subjective hip scoring as a selection criterion. Further, even when dogs considered to be normal on the basis of standard ventrodorsal hip radiographs were mated, a certain percentage (from 19 to 73%) of the offspring could be expected to have CHD.\(^2\)\(^2\)\(^3\) Also, most subjective hip scoring methods require that dogs be older (> 12 to > 24 months old, depending on the method and country) before hip joint status is assessed. This meant that breeders were compelled to follow their instincts when selecting which puppies to keep as potential breeders or were forced to invest substantial time and money in feeding and maintaining many dogs with apparent good breeding potential until 2 years of age.

The initial studies that led to the development of the distraction index (DI) method looked at the hip joint from anatomic and mechanical perspectives. It was observed that the standard, hip-extended radiographic view masked hip joint laxity, because it resulted in a winding up of the tensile elements in the joint capsule.\(^3\) Also, a hydrostatic (vacuum-like) mechanism that critically influenced hip joint stability was discovered.\(^3\) It was conjectured, with support from the literature,\(^4\)\(^8\) that an increase in synovial fluid volume would act to negate the effect of the hydrostatic mechanism in its function to passively stabilize the hip joint.

Mechanical testing instrumentation was then developed to evaluate the biomechanics of the hydrostatic phenomenon and of passive hip joint laxity (ie, lateral displacement of the femoral head from the acetabulum).\(^4\)\(^8\) The first part of the study involved mechanical testing of cadaver canine hip joints to determine the range of flexion/extension, adduction/abduction, and internal/external rotation that was associated with maximal passive laxity of the joint. Relative to the plane of the pelvis, the hip joint position associated with maximal passive laxity was found to be between 10° of flexion and 30° of extension, between 10° and 30° of abduction, and between 0 and 10° of external rotation.\(^4\) Coincidently, the central point in this range of motion approximated the position of the hip joint in a standing dog and was termed the "neutral position." Any deviation from this range was observed to cause a marked decrease in passive laxity. In fact, there was a minimum 50% reduction in measurable passive laxity when cadaver hip joints were oriented in the standard, hip-extended position with internal rotation of the femurs, corroborating the finding that winding up of the joint capsule had a profound effect on passive hip laxity.\(^4\)\(^8\)\(^9\)

The second part of the study involved mechanical testing of canine cadavers to characterize the specific load/displacement behavior of the hip joint when oriented in the neutral position.\(^2\) It was found that in this neutral position the hip joint had a sigmoidal load/displacement behavior; that is, the initial resistance to lateral displacement of the hip joint was low; however, at some point in the travel of the femoral head, resistance to further displacement increased dramatically. The sigmoidal load/displacement behavior of the hip joint explains why the distraction procedure has high repeatability from 1 examiner to the next, even though the applied load is not standardized.\(^2\) Even with wide variation in applied load, the expected variation in DI among examiners is < 10%.

The PennHIP method of hip evaluation requires that dogs be sedated or anesthetized and positioned in dorsal recumbency. A standard, ventrodorsal, hip-extended radiographic projection is also obtained. Two additional radiographic projections are obtained with the hip joints in the neutral position: a compression view with the femoral heads fully seated in the acetabulum and a distraction view with the femoral heads displaced laterally by use of a custom-designed device placed between the legs that acts as a fulcrum on the femur at the level of the ventral aspect of the pelvis. The relative degree of femoral head displacement from the acetabulum is quantitated by calculating DI. The DI ranges from 0 to > 1, with 0 representing full congruency of the hip joint and 1 representing complete luxation. The DI is a ratio scale, meaning that a hip joint with DI of 0.6 has twice the passive laxity of a hip joint with DI of 0.3. The scale is also intuitive: the femoral head of a hip joint with DI of 0.6 can be considered to be 60% subluxated from the acetabulum. The subjective hip scoring schemes are ordinal scales, and the NA is an interval scale; neither is similarly proportional or intuitive. Relative to the NA and OFA methods, the DI measurement is less influenced by errors in positioning. The standard, ventrodorsal, hip-extended radiographic projection is examined, and hip joint phenotype is subjectively graded. This grade is included as part of the PennHIP method to provide radiographic information on the existence and extent of DJD.

**Experimental Support for the DI Method**

There is an expanding body of research to support use of the DI method for assessing susceptibility to
CHD. Since 1993, the DI method has been commercially available under the trademark PennHIP.

Comparisons of hip joint laxity measurement methods—A study was conducted to determine which of the popular hip joint laxity measurement methods yielded the greatest amount of passive laxity. In a population of 142 purebred dogs, hip joint laxity (subluxation) on the standard, hip-extended radiographic view was compared with hip joint laxity on the distraction view. On average, there was 2.5° to 11 (GK Smith, unpublished data, 1995) times as much joint laxity on the distraction view as on the standard, hip-extended radiographic view. For a specific hip joint, the distraction view always had more laxity than did the hip-extended view and often had measurable laxity when the hip-extended view did not have any. Joint laxity on the distraction view was found to be positively correlated with laxity detected during palpation of the hip joint (Ortolani's sign); however, it was not great enough to be predictive (GK Smith, unpublished data, 1994).

None of the dogs in the study had clinical signs of CHD. Therefore, no correlations could be made between clinical signs and measured passive joint laxity, although clearly such an association would be clinically desirable.

Association between passive hip joint laxity (NA and DI) and development of DJD—In a study of radiographs from 142 large and giant-breed dogs (mean age, 1.7 years; range, 1 to 3 years), hip joints with low DI (“tight hips”) were found to be highly unlikely to have evidence of DJD on the contemporaneous, hip-extended radiographic projection. As DI increased, there was an associated increase in the probability that hip joints would have DJD. Interestingly, a DI of approximately 0.3 seemed to be a biological threshold between joints that did and did not develop DJD. One of 67 (1.5%) dogs with DI < 0.3 had contemporaneous radiographic evidence of hip DJD (the dog's DI was 0.29). In contrast, 38 of 75 (51%) dogs with DI > 0.3 had radiographic evidence of hip DJD on the hip-extended radiographic projection. Passive laxity, therefore, in this “loose-legged” pool of dogs with DI > 0.3 was considered to be necessary but not, of itself, sufficient to produce hip DJD.

For the same sample of 142 dogs, there was a similar, although weaker, correlation between NA from the hip-extended radiographic projection and probability of having hip DJD. Unlike the case for DI, however, there was not a recognizable threshold for NA beyond which radiographic signs of DJD were not evident. That is, although probability of having DJD seemingly decreased as NA increased (tighter hips), there was no apparent cutoff for NA above which the probability of having DJD approximated 0. Degenerative joint disease was found in 4 of 45 (9%) dogs with NA > 10°, a previously cited threshold, and only 35 of 102 (34%) dogs with NA < 10° had radiographic evidence of DJD. As was the case with DI, not all dogs with obvious hip subluxation on the hip-extended ventrodorsal radiographic projection had radiographic evidence of DJD (even for hip joints with NA < 92°). This observation was corroborated in a recent longitudinal study of working German Shepherd Dogs and Belgian Malinois.

From the growing body of information, it was theorized that there were 2 types of hip joint laxity: passive hip joint laxity, which was defined as the amount of movement that could be measured in the hips of a sedated dog, in the absence of active muscle contraction and weightbearing, and functional hip joint laxity, which was defined as the amount of translation (looseness) that occurred during weightbearing and would result in wear of the joint cartilage and ultimately lead to DJD. Although functional hip joint laxity is clearly of diagnostic interest, there is currently no means to measure it. Passive hip joint laxity, on the other hand, is a readily measurable quantity. If passive laxity could be shown to precede development of functional laxity and DJD, it would be considered a prerequisite or risk factor for DJD.

Breed differences in passive hip joint laxity—If passive hip joint laxity is a risk factor for subsequent development of DJD, breeds of dogs, such as racing Greyhounds and performance-bred Borzois, known to have a very low prevalence of CHD (< 1%), should have uniformly tight hip joints (ie, extremely low DI). This was the conclusion of 1 published study, and breed-specific differences in passive laxity continue to be identified in the expanding PennHIP database. Mean DI for racing Greyhounds and performance-bred Borzois were significantly lower than those for breeds of dogs commonly afflicted with CHD, such as German Shepherd Dogs, Golden Retrievers, and Rottweilers (P < 0.0001). Greater than 98% of all Borzois and Greyhounds had DI < 0.3, and some have had DI as low as 0.08. This finding further supported the hypothesis that DI of 0.3 represented a biological threshold separating normal, disease-free hip joints from joints susceptible to DJD.

Interestingly, when a similar analysis of breed-specific hip joint laxity from the hip-extended radiographic projection was performed on the same pool of dogs using NA to quantitate laxity, there were no significant differences in hip joint laxity among the breeds included, nor was there a disease threshold identified. That is, the NA in Greyhounds or Borzois was not significantly distinguishable from the range of NA observed in breeds of dogs commonly afflicted with CHD. All breeds appeared to have similar distributions of NA. This breed insensitivity of the hip-extended radiographic method may help to explain the poor reliability of CHD diagnostic scoring methods (objective or subjective) based on this radiographic projection.

Repeatability of DI measurements—In a 3-year study of approximately 140 dogs followed up from 4 months of age, the DI was shown to be more repeatable over time than either the NA or a subjective hip score (similar to that of the OFA). Intraclass correlations between DI measured at 4 months of age and DI measured at 6, 12, and 24 months of age were high (r = 0.82 to 0.87), whereas correlations between NA and subjective hip scores assessed at 4 months of age and NA and subjective scores measured at 6, 12, and 24 months of age were much lower. The lowest repeatability was observed for subjective hip score; in fact, the hip score from 4 months of age was not signifi-
cantly associated with hip score at 24 months of age. Distraction index, therefore, could be measured with acceptable reliability as early as 4 months of age, but NA and subjective hip score could not.

Use of DI to predict development of DJD—A logistic regression model was used to determine whether age, sex, body weight, subjective hip score, NA, or DI were risk factors for development of DJD. Of the hip scoring parameters evaluated longitudinally, DI at as young as 4 months of age was the only significant predictor of development of DJD. The strength of the prediction improved when DI was measured at 6 months and 1 year of age. Although passive hip joint laxity was a risk factor for DJD, it was not, by itself, sufficient to cause DJD in all dogs. It appeared that dogs with DI < 0.3 did not develop DJD within the time span of the study. On the other hand, some dogs with DI > 0.3 developed DJD by the time they were 2 years old, but many (51%) did not. Such dogs were considered by the authors of this study to be DJD susceptible, even though many remained free of DJD well beyond 2 years of age.

Interestingly, in this logistic regression model, the P value for body weight as a risk factor was close to the cutoff for significance. Presumably, with a greater range of body weight among the sample population and with inclusion of more dogs, body weight would have also been found to be a risk factor for DJD. This has been borne out by the work of Kealy et al, who have shown a distinct relationship between body weight and development of DJD in genetically matched, CHD-susceptible Labrador Retrievers.

When breeds of dogs were compared using the logistic regression model, German Shepherd Dogs had a 6.3-fold higher probability of having DJD than did the other dogs in the study. Further, within the German Shepherd Dog breed, each 0.1 increase in DI was associated with a 4.1-fold increase in the risk of having DJD, which supported the hypothesis that “tighter hips are better hips.” A similar pattern was found in Rottweilers, and DI was the only significant risk factor for development of DJD. In Rottweilers, however, each 0.1 increase in DI was associated with only a 2.9-fold increase in the risk of having DJD. This suggests that German Shepherd Dogs are more sensitive to vulnerable to passive hip joint laxity than are Rottweilers or, alternatively, that Rottweilers are tolerant of passive laxity and, therefore, relatively resistant to development of DJD. The difference in disease susceptibility might be explained by the much larger hind quarter muscle mass of Rottweilers, which could prevent conversion of measurable passive laxity into functional laxity that would lead to subsequent development of DJD. Or perhaps, the effect of the sloped top line of the German Shepherd Dog, the “folded up” conformation, multiplies the joint reaction forces of the hip joint, making it more prone to DJD. If such protective factors are at play, a DI cutoff developed to determine which German Shepherd Dogs should be retained for breeding may be unfairly stringent if applied to Rottweilers, which have an inherently greater resistance to development of DJD. This emphasizes the need to develop similar logistic regression models for all popular dog breeds to understand the unique and precise relationship of passive laxity to the development of DJD within each breed. It also underscores the importance of a worldwide database to compile, analyze, and report such information.

Results of studies involving German Shepherd Dogs and Rottweilers have recently received support from the findings of Lust et al, who followed up a small population of Labrador Retrievers and used a similar logistic regression model to relate DI to development of DJD. Distraction indices at 4 and 8 months of age were shown to correlate with later development of DJD, as determined at necropsy. Each 0.1 increase in DI measured at 8 months of age corresponded to a 3.1-fold increase in the risk of developing DJD by 2 years of age.

Measurement of DI before 16 weeks of age—To learn whether DI measurement at an age younger than 16 weeks would also be predictive of development of DJD, a study of 39 eight-week-old German Shepherd Dogs was conducted (GK Smith, unpublished data, 1994). Results indicated that DI at 8 weeks of age was not a reliable predictor of subsequent development of DJD. Thus, it is currently recommended that dogs not be evaluated before 16 weeks of age and that follow-up radiography to confirm DI measured at 16 weeks of age be done at 6 months or 1 year of age.

Relationship between OFA score and DI—In a study of 65 large-breed dogs > 2 years old evaluated by the OFA radiographic procedure and by means of the DI method, dogs graded by the OFA as having mild, moderate, or severe hip dysplasia had DI > 0.3 (mean DI, 0.55). That is, all dogs that the OFA judged to be dysplastic clearly had hyper laxity of the hip joints, as judged by the DI method. The converse, however, was not true. Of the 8 dogs judged to have “excellent” hip joints by the OFA, 4 had DI > 0.3 (mean DI for OFA-excellent dogs, 0.3). Similarly, 22 of the 33 (67%) dogs judged to have “good” hips by the OFA and all 14 (100%) of the dogs judged to have “fair” hips by the OFA had DI > 0.3 (mean DI, 0.35 and 0.50, respectively). Therefore, 39 of the 55 (71%) dogs reported by the OFA to not have DI high enough that they would be considered susceptible to development of DJD.

Heritability of hip phenotype—Whether dogs with DI > 0.3 actually develop DJD in their lifetimes may be of less importance than whether they have the potential to transmit the genes for DJD to their offspring. The “efficiency” of this transmission is embodied in the concept of heritability. Heritability of a given phenotypic trait is a property of the population under study. Therefore, heritability of a trait must be calculated for each breed and each population of dogs. Heritability is an important statistic to understand, because it represents the percentage of overall phenotypic variation attributable to additive genetic effects. The higher the heritability, the more rapid the genetic change that will take place in response to application of selection pressure.
The upper limit for heritability of DI can be estimated as the intraclass correlation coefficient for repeatability of DI measurements over time. In a study of German Shepherd Dogs, the intraclass correlation coefficient of repeatability was between 0.67 and 0.74, suggesting that heritability of DI was high. Heritability can also be estimated by analyzing resemblance in DI of parents and offspring. To accomplish this, a regression analysis of the litter mean is plotted against the parent DI mean. Unpublished estimates of heritability of DI for a group of German Shepherd Dogs was between 0.42 and 0.63, and the upper limit for heritability of DI among a group of Labrador Retrievers was 0.92.

The most rigorous estimates of heritability of DI and hip score are derived from analyses of the full pedigree from a closed population of dogs. The Seeing Eye Inc. has maintained such a colony of dogs intended for use as guide dogs for the blind. Using a derivative-free, restricted maximum likelihood procedure that incorporates the full pedigree structure, Leighton et al. found the heritability of DI to be 0.46 for German Shepherd Dogs and Labrador Retrievers. The corresponding heritability estimates for subjective hip scores determined by a board-certified radiologist were considerably lower: 0.34 for German Shepherd Dogs and 0.38 for Labrador Retrievers. Heritability analyses are ongoing for other populations and breeds of dogs; however, early results suggest that the heritability of passive laxity will be much higher than the heritability of subjective scores of the standard, hip-extended radiographic projection. To the author's knowledge, there are no any published estimates of the heritability of the OFA hip score. Higher heritability means that when DI is used as a selection criterion, more rapid progress in reducing the incidence and severity of CHD can be expected.

Summary and Conclusions

The DI method was developed, at least in part, because of perceived variations among radiologists in regard to subjective hip scores assigned to radiographs. It also was recognized that the prevalence of CHD among many dog breeds was disturbingly high, despite efforts to lower the prevalence using subjective score as a selection criterion. The DI method was developed on the basis of results of mechanical testing of cadaver hip joints, which accomplished 3 principal objectives. First, it showed that when the hip joint is in the standard, hip-extended, internally rotated position, passive laxity is minimized. Second, it showed that passive laxity was maximized when the hip joint is in the neutral position. Third, it demonstrated the sigmoidal nature of the load/displacement curve for the hip joint in the neutral position, which suggested that high repeatability from examiner to examiner in regard to DI could be expected without the need to standardize applied force. The mean and range of DI were shown to vary from breed to the next, but within an individual dog, DI appears to remain constant (within limits of scientific acceptability and clinical applicability) from 16 weeks of age. Passive hip laxity measured on the distraction view is, on average, 2.5 to 11 times greater than that measured on the standard, hip-extended radiographic view. Performance Borzois and Greyhounds, which have an extremely low prevalence of CHD, uniformly have tight hip joints (DI < 0.3), and mean DI for dog breeds that have a high prevalence of CHD is significantly greater than mean DI for Borzois and Greyhounds. However, individual dogs that have DI < 0.3, even though members of breeds prone to CHD, have a low risk of developing DJD. Some, but not all, dogs with DI > 0.3 will develop DJD by 3 years of age, and DI has been shown to be the principal risk factor for development of DJD. Susceptibility to development of DJD appears to be breed-specific. For example, given an equivalent DI, German Shepherd Dogs are more at risk for developing DJD than are Rottweilers. Heritability of DI is higher than that of the subjective hip score; thus, selection pressure based on DI should result in faster genetic change than selection pressure based on subjective hip scores. Finally, the DI method has been performed on approximately 14,000 dogs, some of which were evaluated multiple times. It is apparent that this method is no more harmful than the standard, hip-extended radiographic method or palpation performed as part of a routine orthopedic examination.

References


Book Review:


This book complements existing equine medical texts by providing step-by-step instructions for diagnostic techniques applicable to adult horses that will be a valuable reference for those inexperienced in equine medicine. The text is organized on the basis of techniques used to evaluate each body system. For easy reference, appendices that summarize the diagnostic approach for commonly encountered problems in horses are included. The text is concise and easily understood, and clarified even more by the numerous illustrations. Sufficient detail is provided to allow students or practitioners to approach an unfamiliar technique with confidence. The sections on transrectal examination, lameness evaluation, and evaluation of the respiratory system are particularly noteworthy. Although the authors have made a commendable effort to describe all available diagnostic techniques, diagnostic tests for Potomac Horse Fever, and equine protozoal myeloencephalitis are not discussed. Also, more detailed information regarding the interpretation of diagnostic tests is desirable, although the authors do provide sufficient information to narrow down the list of diagnostic possibilities. Despite the somewhat high price, this textbook is a valuable reference for veterinary students, new graduates, and veterinarians who do not specialize in horses.

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